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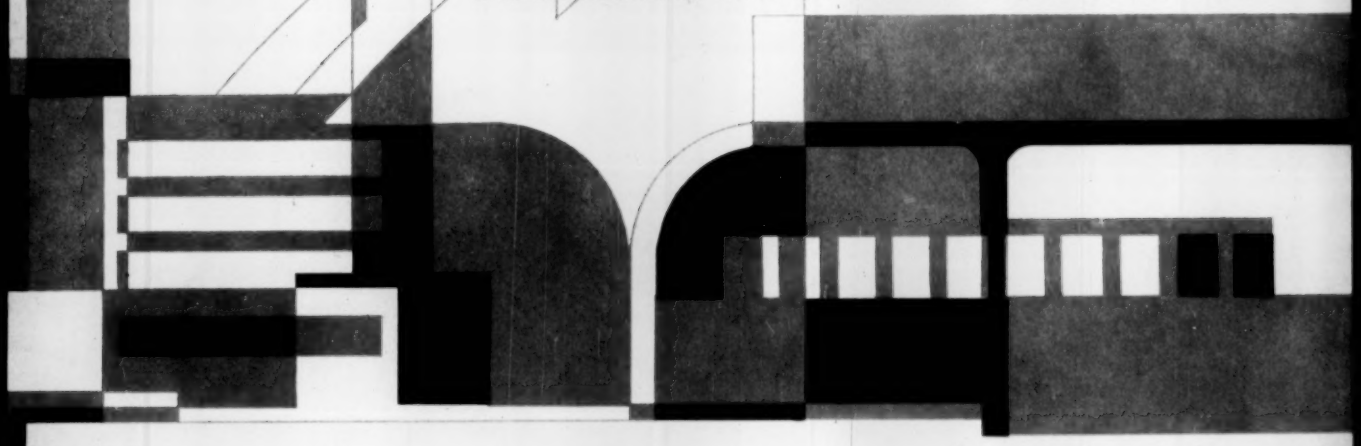

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The One Best Life at Eighty: Dr. Lillian M. Gilbreth and the Unceasing Quest

by **WILLIAM J. JAFFE**

Professor in Management Engineering, Newark College of Engineering

ATTEMPTING to pay homage to Dr. Lillian M. Gilbreth by merely listing her biographical data—born: Oakland, California, May 24, 1878; B.Litt. (1900) and M.Litt. (1902), University of California; Ph.D. (1915), Brown University, etc., etc.—would at one and the same time be both exceedingly lengthy and woefully inadequate. In the first place, almost everyone, from the moviegoer through the engineer, both here and abroad, knows about many of her accomplishments. They can recite many facts about the wonderfully rich life of all of her family, the work in motion study, the fight for the elimination of fatigue, the contributions made to the work-a-day lives of the disabled and the cardiac, the applications of psychology and physiology, the analyses in the form of process charts and micromotion studies, the professorships at Purdue, the University of Wisconsin, and the Newark College of Engineering, the honorary memberships and fellowships at the American Institute of Industrial Engineers, the American Society of Mechanical Engineers, the American Management Association, the American Home Economics Association, the Society for the Advancement of Management, the British Institute of Management, the Engineering Institute of Canada; the awards in the form of the Washington Award, the Gantt Medal, the Wallace Clark Award, the Award of the National Institute of Social Sciences, the Gilbreth Medal, the dozen or so honorary degrees, and the many more matters with which she has been concerned in her "Quest for the One Best Way." Furthermore, there are few libraries, in even the smallest hamlet in the most remote part of the world, that cannot boast at least a copy of her children's books, the Spriegel and Myers collection of the Gilbreths' writings, Yost's biography of her partnership, and maybe her very own *The Quest of the One Best Way*. In addition it would be impossible—and she would be the first to say so—to write about her without referring to *the* partnership that began on a June day in 1903 in the Library of the City of Boston. But, most important, putting Dr. Gilbreth's career—much less, her vibrant force and stream of movement—as a mere listing would be as meaningful as a newspaper photograph of a colorful and rhythmic ballet performance.

Perhaps it would be best to allow Dr. Gilbreth's own literary style set the scene:

> Montclair! Who can describe its beauties on a June morning with the pink flowers in full bloom; the lilacs just beginning to go; the lilies of the valley still beautiful; with the rhododendrums just beginning to come out and the iris, purple and white; with the wisteria in its full glory; the lawns velvet carpets and the beautiful trees everywhere; with the summer sunshine pouring down and the Sunday quiet over everything? It is a dream of beauty.

If we may move the year to 1924, we would note that the Gilbreth family was in full swing of its customary planning. On June 13, one of the children would graduate from high school—to be followed by an ice cream party that evening and Class Day on the 14th. And, in less than one week, the two partners, Frank and Lillian, were to sail on the *Scythia* with a party of engineers to present papers at the World Power Congress in London and the International Management Congress in Prague. Of course, during this week, too, the children's schools were to close for the summer, the children settled at Nantucket, and the many other matters settled. And so *the* telephone call came—Major Gilbreth calling from a booth at the Lackawanna Station in Montclair—and Dr. Gilbreth answered. As she has written,

> Suddenly, on June 14, 1924, Frank went, not abroad, as he had planed, but "West," as soldiers go.

But this brought to an end only the physical aspects of the partnership—the marriage with the "non-skid wedding ring," the working association, the mutual love, understanding, and admiration. But The Quest went on. . . .

The writers of the popular *Cheaper by the Dozen* remarked about "the change in Mother." Decisions, which had first been made for her by her parents and then by her husband, were a thing of the past. Her fears "of fast driving, of airplanes, of walking alone at night" were gone. She was unafraid and could not be upset, "because the thing that mattered most had been upset."

On Major Gilbreth's death, the Family Council, as always, met. Matters were discussed and decisions reached. According to his wishes, his brain went to Harvard, for, after all, in his usual humorous but serious manner, he had written previously to Myrtell Cañavan, the Boston brain specialist: "My hat is seven and three-

eighths, in case you want to get a jar ready." But his request that his ashes be scattered near the house was denied, and Lillian Gilbreth, with the bravery and courage that are hers, was rowed out in a boat, and she herself scattered her beloved husband's ashes into the currents of the waters surrounding New York. The children were to remain in school, and she was to "further Frank's work." She began by going abroad and reading the papers at London and Prague.

A typical expression of her feelings, modesty, and ambitions, appears in a short note which she wrote from Nantucket on August 28, 1924, to Professor William S. Ayars, who, before coming to Columbia University and while on the faculty of the Nova Scotia Technical Institute, had attended the Gilbreths' Summer School in Scientific Management at Providence in 1912:

> Thank you so much for your letter. It has just reached me, for I'm just back from two months abroad. . . .
>
> Your letter gives me new courage. I do so want to carry on all Frank's works and plans. It helps me to know that you believe I can.

Her success is well known, but, in her plan for the future, it was her family that came first. In the biography of the partnership, Edna Yost alludes to a comment made by Dr. Gilbreth who had started, but could not finish, a biography of a well-known archeologist because of the demands he had made on his son: "What is it, in some people, that permits them to treat children as something they own?" The reaction of the Gilbreth children to her efforts is best expressed in the Dedication in *Cheaper by the Dozen*:

> TO DAD
> who only reared twelve children
>
> and
>
> TO MOTHER
> who reared twelve only children.

Relatively speaking, so many of us have come so recently into the field that, as we watch this gracious lady at an engineering conference and observe the respect and attentiveness that she receives, we either do not know or do not realize that she did not attain this high status automatically.

Thus, despite such recognition that Alford gave the Gilbreths' and motion study in his 1922 ASME report (Ten Years' Progress in Management) and the honors afforded by the old Society of Industrial Engineers and the Masaryk Academy, the Gilbreths' work had much less than universal appreciation. For example, so well-known and widely distributed a classic as Hunt's *Scientific Management since Taylor,* in 1924, failed to give any space to the Gilbreths, to motion study or even to the process charts. Moreover, it was not until 1930, that the *Engineering Index* stopped listing "Motion Study" under "Time Study."

Clearly, her position did *not* come easily. Of course, there were two of them for about a quarter of a century —but for an even longer time, he was only at her side spiritually.

What was it that originally made Lillian Gilbreth so unacceptable? Her ideas? Her sex? Individually and collectively, they were *both* matters of great concern for many years to an immature industrial society and its masculine mentors.

Although she earned a Ph.D. from Brown, a few years earlier, when she had submitted her thesis on "The Psychology of Management" to the University of California she was informed—contrary to her original understanding—that one year of residence was necessary. Her busy life and responsibilities prevented this. However, her husband, feeling that the work was of such importance that no time should be lost in getting it into print, soon discovered that few publishers saw any market for such subjects—especially as written by a woman. The magazine, *Industrial Engineering,* did publish it under the then none-too revealing name of "L. M. Gilbreth." Later Sturgis and Walton brought it out in book form—with the author's name in the same "cryptic" form plus the understanding that no publicity was to be given to the fact that the author was a woman.

If, even today there is unfortunately an incomplete acceptance of women in all engineering roles, what must it have been *then?* Invited to be among a group of engineers to greet Baron Shiba at the University Club in New York, Dr. Gilbreth cut short a business trip—only to be stopped at the door by a uniformed doorman. Again, as a member of an ASME committee, which was to meet for breakfast at the Engineers Club, it was suggested that she get her breakfast elsewhere.

Nevertheless, influenced by her husband's great respect for ASME and by friends like Wallace Clark, she did not confine herself to management and industrial engineering circles. Consequently, when ASME's Management Division, in 1935, asked her to conduct the first session on "The Psychology of Management" at the Engineers Club, she accepted and was met at the door by Clarence Davies who warmly ushered her into that masculine *sancta sanctorum.*

A willing pupil of her husband, she was led from the terminology used in masonry and concrete work to the study of motions. As much as he inspired her, she inspired him. Thus, the "cyclegraph" came when she could not visualize breaks in the rhythms of the curves. But, on the other hand, it was she who made him more keenly aware of the human element. It was she who took the teaching lead when her opinions on human nature differed from his, and it was she who opened the huge psychological storehouse. It is certainly not easy to say who inspired whom and what reinforced what: Newton's Third Law is quite expressive of this mutuality of forces. The result, however, was unmistakable: the Gilbreth achievement was more than a mere development of motion study as a management tool. While Taylor looked

at the worker from the outside, the Gilbreths also looked on the inside. Their search for "The One Best Way" was not limited to motions and it was not confined to the industrial plant. They called on psychology, on physiology, and on all the social studies to help increase the worker's worth to himself, to industry, and to society. In the broadening of the aims and accomplishments of management, it was Lillian Gilbreth who took the lead in this virgin field.

It is both easy and difficult to analyze this First Lady of Engineering. She is the epitome of crystal-clear logic —even though she seems to be a mass of contradictions. Trained in literature, she has found her place in engineering. As an engineer, she has found people more important than machines; waging a never-ending war on fatigue, one, watching her unceasing rounds of work, activity, and travel, can rightfully believe that she has created a non-existent foe. An extremely busy woman, she seems to have more time for more things than most people. And, as kind and as gentle as she is, she can don armor and do more than hold her ground in defending the right.

Indicative of her skill, courage, and fidelity is the stand she took during the schism that arose between motion study and time study. Because time has dulled the differences of opinion, because she played no little part in setting the facts straight, and because no account of the Gilbreths can avoid it, a brief mention of it must be made here.

Although Frank Gilbreth was a keen admirer of Taylor's genius, he was enough of an individualist to take pride in his own progeny, especially when Taylor, in a single swoop—see, for example, Taylor's *Principles of Scientific Management*, pp. 80-1—identified motion study with time study. Besides, the Gilbreth work had been done "without the direction of Taylor," it had been performed without the aid of Taylor's "direct disciples," and it had been conducted along "slightly different lines." Then there were numerous irritations. For example, at Birmingham, in 1910, Gilbreth felt that Taylor had made some mistatements which he thought would be corrected when they appeared in print. Not only were they repeated but, instead of Gilbreth's statement that he would submit a paper on the subject, the record said that he "had nothing to add." As early as 1898, Gilbreth was shocked on watching one of Taylor's "disciples" who appeared on one of his construction jobs and started to time men without any consideration for "The One Best Way." Of course, the secret timings, which Taylor himself later regretted, were scorned by Gilbreth from the beginning. Despite his excellent relations with the unions, Gilbreth took his place on the side of scientific management and reaped some of the whirlwind that was probably directed at Taylor. Gilbreth was very unhappy, too, when Taylor once relegated the role of micromotion studies to investigations in which one might be interested only in "the minutiae of motions." Certainly Gilbreth could not understand the cry of "expensive" when he felt that so little attention was paid to the economies that it could produce. And there were other instances.

Through it all, Lillian Gilbreth stood at her husband's side, but she insisted that their work go on. However, Major Gilbreth did deliver a paper on "Time Study and Motion Study as Fundamental Factors in Planning and Control"—to which he added the subtitle "An Indictment of Stop-Watch Time Study"—at the Taylor Society. The *Bulletin* of the Taylor Society also accepted Lillian Gilbreth's "The Relations Between Time Study and Motion Study." But the general recognition of the work of the Gilbreths was slow. Even the process charts, in spite of ASME's publication of them, went unrecognized for a long time. As a matter of fact, the Taylor Society's *Bulletin*, in printing an obituary of about a hundred words on Frank Gilbreth, spent only three in describing him ("Engineer, Investigator, Author"). It gave his dates (July 7, 1868-June 14, 1924), but it devoted the remainder of the article to the fact that it was Gilbreth who had the idea of establishing an "organization to perpetuate . . . (Taylor's) . . . work."

But Frank Gilbreth, on the other hand, needed no society to commemorate him. Without deprecating Taylor, his genius and accomplishments, when he died, he left some writings and a fast dwindling group of disciples who worked *under* him. Frank Gilbreth, on the other hand, left a vital philosophy plus the living monument that is Lillian Gilbreth. In "furthering Frank's work," she, if we may borrow from the sonnet she wrote commemorating Gantt, devoted herself to

> . . . a Cause. . . .
> The winning of a New Industrial Day.

And so Lillian Gilbreth has taken The Quest through factories, stores, colleges, and societies throughout the world. And all this—without flourish, noisy fanfare, or publicity. According to Edna Yost, as recently as 1945, when the Chicago S. A. M. Chapter released some of the films that the Gilbreths had made, people of such import as David Porter, Ralph Barnes, and Allan Mogenson soon discovered that some of the work they had done was actually a duplication of what the Gilbreths had done many years before. Her friend, Marie Sealy, who did so much in the retailing field, still speaks fondly of Dr. Gilbreth's "Institute in which she trained representatives from industry in motion study and the Gilbreth Philosophy of Management." These endeavors were abandoned only when, their mission accomplished, the engineering schools took over. As for her travels, to quote Miss Sealy, again, "even the Internal Revenue District knows of it, for they questioned her traveling expenses but were easily convinced when they saw her airplane ticket records." As for the help she gives friends, acquaintances, and, to speak personally, doctorate candidates, there does not seem to be any limit.

A very meaningful tribute was paid to her by Professor Joseph A. Rich, Jr., who was a member of the Department of Personnel Relations she chaired at the Newark College of Engineering. "Each week, no matter how busy, she would sit down with every member of the department, discover the disturbing problems, if any, and offer mutual understanding and solutions. In the personnel field, she was almost unique; she practiced what she preached!"

Mrs. Wallace Clark said that last year, in Wuppertal, West Germany, Dr. Gilbreth conducted a ten-weeks management seminar in German at the Technische Akademie. She "blew out the 79 candles on the cake in the home of the Chairman of the Board of the Akademie." This year the Metropolitan New York Chapter of AIIE is proud to be host at one of her eightieth birthday celebrations.

However, one does not have to attend or wait until the cake is cut to make the wish: "Many Happy Returns!"

Hyperenthusiastic and Hypercritical Writings on Predetermined Motion Times

by **EDWARD V. KRICK**

Assistant Professor, Department of Industrial and Engineering Administration, Cornell University

TOO many authors on the topic of predetermined motion times may be classified on the basis of the points of view they express as either hyperenthusiastic or hypercritical. The hyperenthusiasts make liberal use of such words and phrases as "accurate," "they work," "provide true standards," "eliminate judgment," and similar assertions. Their articles frequently are "success stories," describing the rosy situation brought on by installation of a particular predetermined motion time system. Their evaluations of the technique usually lack objectivity in that they report a biased picture of their experience with predetermined motion times, or fail to cite important assumptions, pitfalls, and known or potential sources of error. Their evaluations reflect a strong enthusiasm which appears highly subjective in origin.

Writings of the hypercritics may be identified by such quotes as "dangerous to use," "be wary of such standards," "meaningless," "an impossibility," "little predictive value," and "invalid." Their articles frequently describe one or several studies which indicate that errors (of an unestimated magnitude) will result if standards are set with a predetermined motion time technique, then proceed to generalize that the technique should therefore be avoided. Their evaluations of the technique lack objectivity, but in this case in the form of failure to weigh the practical consequences of unjustified assumptions, failure to recognize certain unique advantages offered by the technique, failure to compare the probable error with that of alternative procedures rather than with an abstract and unobtainable level of perfection, or failure to adhere to accepted methods of inference. Their evaluations reflect pessimism and impracticalism, and at times they become as subjective in their statements as their counterparts.

SOME CLAIMS MADE BY HYPERENTHUSIASTS

The term scientific is a byword among ardent proponents of the predetermined motion time technique, and although the matter is not of serious practical consequence, the frequency with which this word is misused tempts some comment. Description of this technique as scientific is justified if the system has been developed according to a certain set of rules conventionally followed in the derivation of knowledge. These rules require such procedures as the formulation and testing of hypotheses, collection of sufficient amounts of data, the making of inferences, statement of assumptions, estimation and statement of experimental error, full disclosure of all of these, etc. No evidence is available to support the contention that any current predetermined motion time system was so developed, and that any of them have been is highly doubtful. Of course, it is not necessary that such a technique be scientific in order to produce satisfactory results.

Proponents frequently describe the predetermined motion time technique or a particular system of same as accurate. Accuracy, however, is a matter of degree, it is not bilateral. What a particular writer may mean by the term accurate is any one of a *large range* of degrees of exactness, depending upon his ability to judge this characteristic and upon the stringency of the standard he uses for judging it. Therefore, by itself "accurate" is an indefinite term. Without qualification it should not be taken seriously by the reader.

Perhaps more important than this careless and misleading use of the term accurate, is the problem of the measurability of accuracy. Accuracy is the degree of bias contributed by a measurement system to the estimates it

produces.[1] To estimate accuracy, it is necessary to know the true value, or at least have a technique for estimating it that is "more accurate" than the one we are evaluating. If there is a technique that is *known* to be "more accurate" than predetermined motion times, what is it and how do you know that it is more accurate? In the answer to this question lies the reason why comparison of estimates derived from predetermined motion times with rated stop watch times does not justify a statement about accuracy of either technique.

A statement or implication that the predetermined motion time technique or a particular system "works well," "works," or "works satisfactorily" is quite indefinite and subjective. There are a number of reasons why a statement of this kind should not in general be taken seriously. For instance, industrial environments differ radically so that what "works" in one situation may not in another. Furthermore, we can hardly expect a salesman or user of predetermined motion times to write about the cases in which it didn't work! And too, the statement "works satisfactorily" has little meaning unless we know the criteria used in arriving at that opinion. Since the decision involved here is primarily subjective and the factors deceptive, it is quite possible that what is judged satisfactory by one user may not seem at all so to others. For example, some merely want something that works in the sense that there is a minimum of friction and that life is peaceful and simple, and so they are easily satisfied. Those few writers who do describe their criteria cite some rather unsound bases for reaching the conclusion they have. To illustrate:

a. Extensive savings through improved methods are claimed to result from installation of a predetermined motion time system. Yet, some portion of this saving has resulted merely because attention has been given to work methods in the process of applying the system, attention which could be given without the benefit of a predetermined motion time system. There is good reason to suspect that this portion is appreciable, especially in view of some of the examples that writers have described to illustrate how the technique has been "responsible" for better methods.

b. Standards set with a predetermined motion time system are claimed to compare favorably with prevailing standards in the company or with a group of standards specially set by another method (usually stop watch time study) for purposes of comparison. Yet it cannot be denied that considerable judgment and interpretation are required in the selection and classification of motions under any of the current systems, and that it is quite possible, in fact very easy, to permit previous time study experience to influence these selections and classifications to the point where favorable agreement between the results is obtained. Thus, though perhaps unintentionally, the results of the two methods can be *made* to compare satisfactorily. The extent to which this practice takes place would probably come as a surprise to some. Even if the results of the two methods do actually agree closely, this means no more than just that. But why expect agreement? Stopwatch time study has an objectionable error associated with it, so how can any method that agrees with it be any less in error? When and if a more accurate and precise system does come along, will we reject it if the results do not agree with stop watch time standards?

c. It is stated or implied that employees seem more satisfied with the new system. However, the absence of employee complaints is not necessarily an indication that the standards are accurate.

Another source of weakness in almost any statement about how well a work measurement method works is the difficulty involved in satisfactorily estimating the degree of error present in any standard or group of standards. The limitations of attempting to estimate this by comparing times set by two different methods, predetermined motion times and stopwatch time study for example, have already been discussed. Another practical alternative is to use the actual performances of operators working under the standards as the basis for evaluating the error. This is commonly done by observing the ratios of "actual to standard" and noting evidence of tightness and particularly of looseness. Aside from the philosophical flaw in such a procedure, is the fact that actual output under a time standard is strongly influenced by the standard itself. In the case of loose standards at least, employees tend to maintain a ratio between actual rate and standard rate of output which they believe is expected by the company, by judicious regulation of their output. Thus, loose standards are *made* to appear satisfactory. Therefore, basing a conclusion as to the satisfactoriness of a set of standards upon the number of tight standard complaints and high earnings cases is an unreliable procedure.

The claim that use of predetermined motion times eliminates judgment from the process of setting time standards is completely unjustified. In fact the total judgment demanded may not be any less than that exercised in stop watch time study. It seems, however, that the judgment required in application of a predetermined motion time system occurs in the form of many decisions, each of which by itself is of less consequence than selection of a rating factor. Whether or not this reduces the net effect of judgment in application of such systems apparently depends primarily upon the degree to which the applicators are biased.

SOME HYPERCRITICAL CLAIMS

The viewpoint of these authors seems to be that the technique should be avoided, or that its usage should be drastically curtailed. Such conclusions are sometimes based upon some research concerning a particular assumption, or a comparison of systems. A popular subject for these investigations is the effect of the context of a motion on its performance time. If the particular assumption is shown to be violated, the writer usually proceeds to make the generalization that such systems "are dangerous to use," "invalid," "meaningless," etc. There are several flaws in this generalization process.

First, these investigators usually study one task with one or several subjects. Statistical significance under

[1] As opposed to precision, which is the variation contributed to the measurements by a measurement system. Also referred to as the reproducibility of a measurement.

these circumstances is not sufficient to justify the generalizations made. Before extending findings beyond the particular task and subjects used, other individuals and tasks must be studied because differences in results are expected among them.

Second, these investigators are usually content with testing a hypothesis, for example, that a motion time depends upon its context. If this hypothesis is accepted as is usually the case, they proceed to make a drastic generalization such as the claim "dangerous to use." But there is no doubt that the times for some motions depend upon the nature of other motions in the task. The relevant question to be answered is *to what extent* do motion times depend upon their contexts? We are interested in an estimate of the error resulting from the effect of context on motion times, not merely in whether or not there is an error. This technique cannot justifiably be condemned for violation of an assumption when the extent of the violation is unknown.

Third, these investigators fail to estimate the practical consequences of violation of the assumption before they condemn the system. Granted the context of a motion influences its performance time, but what error does this ultimately cause in time standards estimated by this technique? Even knowing to what extent context may be expected to influence a motion time does not tell us what the net effect is on the standards obtained, for two reasons:

a. As a consequence of this error, for a particular task it is probable that the standards for some motions will be tight and others loose. The probable net effect is that the *expected* error (due to this cause) of the cycle time estimate will be less percentage-wise than the expected errors of the individual motions, because of some compensation. This should not be construed as a statement that the error is thus eliminated or rendered negligible. The point is that this is a likelihood which authors are responsible for investigating before they make their condemnation.

b. It is quite possible that some of the effects of context may be accounted for in the structure of a predetermined motion time system. This may make the system more cumbersome to apply, but the possibility certainly exists and is not unreasonable.

Fourth, and probably most obvious, is that these authors attempt to condemn the technique on the basis of its own error without evidencing recognition of the practical problem facing management, which must have time estimates to operate successfully. Currently there are available a number of methods of estimating time standards: purely subjective estimates, production records, work sampling, stop watch time study, predetermined motion times, and macroscopic standard data. Each of these has a sizeable inherent error, yet no method is arbitrarily rejected because of this. Clearly the problem involves comparison and selection from a number of imperfect alternatives. Just as clear is the absurdity of abstractly rejecting the predetermined motion time technique, or any other method, because it has been shown to be imperfect.

Furthermore, the hypercritical authors seem to ignore a worthy feature of this technique which makes it useful where methods demanding actual observation are not. The synthetic nature of predetermined motion times makes the technique very useful in methods design work, where time estimates are desired for alternative manual methods still in the conceptual stage. This synthetic feature also makes it possible to establish time standards on operations in advance of actual setup and production. If eventually the accuracy and precision of standards established by predetermined motion times should be demonstrated to be inferior in competition with actual observation methods, it may well be that it will be retained for use where the latter methods are ineffective, i.e., where a time standard is desired in the pre-production stage. Thus it seems unrealistic to speak of outright rejection, for this and other work measurement methods have certain features that make them uniquely useful for different types of problems facing management.

Aside from this, it is not probable that any one work measurement method will prove superior for all types of operations, production volumes, products, industrial environments, etc. It seems likely that different techniques will prove superior under different circumstances.

In summary, the predetermined motion time technique cannot be completely and arbitrarily rejected simply on the basis of imperfection, for several reasons, namely:

a. The alternatives are imperfect also, and as yet the *degrees* of imperfection of various methods are unknown. Most will concede that stop watch time study results contain an undesirable error but this does not stop people from using it.

b. It is unrealistic to talk of *complete* rejection, for the technique will at least be useful for some purposes because of the synthetic nature of its results.

c. Variation in characteristics of the tasks for which time standards must be obtained and differences in conditions make it seem likely that each work measurement technique will be superior under some circumstances.

In any event, the predetermined motion time technique should not be judged on the basis of characteristics of the current versions, for these have faults not inherent in the method. Such defects are correctable and either existing systems will be revised or superior ones will supplant them. This is one reason why attempts by some investigators, to "prove" that the times allowed by various systems for certain motions differ significantly, are of doubtful merit. Of what consequence is it to show that these differences in motion times exist, differences which are inevitable in light of the variation in performance level, motion definitions, and breakpoints among systems? Certainly the standards established by various systems will not *necessarily* differ appreciably because there are differences among the systems in individual motion times. Furthermore, standards estimated by different systems may differ appreciably and still be no cause for concern. That is, if the standards estimated by two predetermined motion time systems (for the same group of operations) differ by a reasonably constant ratio, no

problem exists. If the values arrived at by the two systems are not reasonably correlated, then one system is more accurate and precise than the other, and this *is* important in selecting a system. In summary, showing that motion time values differ among current predetermined motion time systems does not provide sufficient basis for condemning these systems, let alone the technique in general. In fact, what do such incomplete comparisons accomplish?

SOME COMMENTS ON THE HYPERCRITICISM

It may be that the purpose of this hypercriticism and the research supporting it has been to counter-balance assertions made by hyperenthusiasts and to destroy a certain complacency. The value of such an endeavor is questionable for research of a more constructive nature is presumably being supplanted by these nonconstructive efforts. The need is for investigations devoted *first* to minimization, *then* evaluation, of the error involved in the predetermined motion time (or any other) technique. The need is not for attempts to prove that there is an error or that systems differ. Papers and articles of these hypercritics make interesting reading, but what contribution has been made?

A MIDDLE OF THE ROAD VIEWPOINT

The prestige of Industrial Engineering and the media[2] by which these two types of spokesmen publish would be enhanced if such unilateral evaluations of the technique could be minimized.

As for writers who tend to be hyperenthusiastic, a greater service would be provided if an attempt were made to be more objective and to curb the effects of personal enthusiasm on their writing. Yet if one desires to say much on this topic some subjectivity must be introduced. There is no particular objection to this as long as these statements are identified as opinion. Thus, for example, unless a writer has concrete evidence to support his contention that a predetermined motion time system "works better," he should explicitly label his statement as opinion. And too, there should be willingness to admit the probability of error in observations and conclusions reported, and to avoid the unjustified implication of certainty. Furthermore, these writers should recognize this and other time measurement methods as the estimating techniques they are, and acknowledge that error is involved. Finally, they should adopt a middle of the road position and relate the unfavorable as well as the favorable aspects of their experiences with the technique.

As for the writers who tend to be hypercritical, they too should be more realistic in their appraisals. Why not judge the technique in the context of imperfection in which it exists and recognize its unique advantages? And if research is to be attempted, why not dedicate it to improvement rather than condemnation?

[2] The *Journal* has been reasonable in that at least it has presented both viewpoints. But certain other periodicals have been guilty of exclusion of critical articles to the point where one wonders what service these periodicals are really providing their readers.

REFERENCES

(1) Abruzzi, Adam., *Work, Workers, and Work Measurement*, Columbia University Press, New York, 1956.

(2) Abruzzi, Adam., *Work Measurement*, Columbia University Press, New York, 1952

(3) Abruzzi, Adam., "Developing Standard Data for Predictive Purposes," *Journal of Industrial Engineering*, November, 1952.

(4) Boyce, C. W., "How Good Is MTM?", *Factory*, Vol. 108, August, 1950.

(5) Brady, P. J., "Work Factor Analysis Saves Money, Time, Complaints," *Factory*, Vol. 109, No. 6, June, 1951.

(6) Davidson, H. O. *Functions and Bases of Time Standards*, American Institute of Industrial Engineers, 1956.

(7) Freedman, P. S., "A New Way to Measure Work in Shoe Factories," *Leather and Shoes*, December, 1949.

(8) Gomberg, W. *A Trade Union Analysis of Time Study*, Second Edition, Prentice-Hall, Inc., New York, 1955.

(9) Lynch, H., "Basic Motion Timestudy," *Journal of Industrial Engineering*, August, 1953.

(10) Maynard, H. B. Et Al., *Methods-Time Measurement*, McGraw-Hill, Inc., New York, 1948.

(11) Morrow, R. L., *Motion Economy and Work Measurement*, Second Edition, Ronald Press Co., New York, 1957.

(12) Mundel, M. E., and Lazarus, I. P., "Predetermined Time Standards in the Army Corps," *Journal of Industrial Engineering*, Vol. V, No. 6, November, 1954.

(13) Nadler, G., "Go Slow on Predetermined Motion Times," *Manufacturing and Industrial Engineering*, Vol. 31, No. 4, April, 1953.

(14) Nadler, G., "Critical Analysis of Predetermined Motion Time Systems," *Proceedings of the National Time and Motion Study Clinic*, Chicago, 1952.

(15) Nadler, G. and Denholm, D. H., "Therblig Relationships: I—Added Cycle Work and Context Therblig Effects," *Journal of Industrial Engineering* Vol. VI, No. 2, March–April 1955.

(16) Niebel, B. W., *Motion and Time Study*, Richard D. Irwin, Inc., Homewood, Illinois, 1955.

(17) Quick, Shea, and Koehler, "Motion Time Standards," *Factory*, May, 1945.

(18) Reiss and Pigage, "The Incompatibility of Predetermined Motion Time Systems," American Society of Mechanical Engineers, Paper 84-F-5.

(19) Rowe, A. J., "Applicability of Standard Data for Production Scheduling," *Journal of Industrial Engineering*, Vol. VI, No. 6, Nov.–Dec., 1955.

(20) Segur, A. B., "Motion Time Analysis," *Proceedings of National Time and Motion Study Clinic*, Chicago, 1948.

(21) Stewart, T. C., "Work Factor Analysis Takes Stopwatches Out of Time Study," *Factory*, Vol. 106, No. 5, May, 1948.

(22) Tiedemann, F. C., "Is MTM Applicable in Apparel Plants?", *Apparel Manufacturer*, Nov., 1950.

(23) White, K. C., "Predetermined Elemental Motion Times," American Society of Mechanical Engineers, Paper 50-A-88.

(24) "Timing a Fair Day's Work," *Fortune*, October, 1949.

A Simple Explanation of Simplex Calculations

by **PAUL H. RANDOLPH**

Associate Professor of Industrial Engineering, Purdue University

IT HAS been often said that although the word "simplex" appears in the title of the general computational algorithm of linear programming, the method itself is anything but simple. This misconception is probably due to the fact that until recently the only text on linear programming based its theoretical background on matrix algebra (1). Thus, most articles intended for the average engineer (who does not know matrix algebra) have been of a "cookbook" nature, giving step by step directions for finding a solution to the problem. Rarely do these articles give a reason *why* these procedures are to be followed, but concentrate only on *how*.

Fortunately, the computational procedures of the simplex method can be readily understood by one with no more training than ninth grade mathematics. The purpose of this article is to explain *why* the simplex method works in the simple terms of elementary algebra. This explanation will be based on one theorem which will not be proved here.

THE PROBLEM

Although numerous examples of linear programming problems appear in the literature, let us quickly review two examples to establish a standard form of the linear programming problem. Let us first consider an example by Noble in which two grades of paper are produced on a paper machine (7). Due to raw materials restrictions not more than 400 tons of grade 1 and 300 tons of grade 2 can be produced in a week. Let the numbers of tons of grades 1 and 2 produced during the week be denoted by x_1 and x_2 respectively. Then,

$$x_1 \leq 400$$
$$x_2 \leq 300.$$

It requires 0.2 and 0.4 hours to produce a ton of grades 1 and 2 respectively. Since there are available 160 production hours each week, it is evident that

$$0.2x_1 + 0.4x_2 \leq 160$$

or

$$x_1 + 2x_2 \leq 800.$$

The profit p for the week is given by the function

$$p = 20x_1 + 50x_2,$$

showing the profit to be \$20 per ton of grade 1 and \$50 per ton of grade 2. The problem is to determine the non-negative values of x_1 and x_2 which satisfy

$$\begin{cases} x_1 + 2x_2 \leq 800 \\ x_1 \leq 400 \\ x_2 \leq 300 \end{cases} \qquad \text{Eq. 1.}$$

and which *maximize* the profit function

$$20x_1 + 50x_2 = p. \qquad \text{Eq. 2.}$$

In a second example of this same article, Noble gives a problem of feed mixing. This example is characteristic of many mixing or blending problems in the process industries. A cattle feeder wishes to purchase four special feeds F_1, F_2, F_3, and F_4 in order to supply the proper minimum vitamin content to his feed mix. Table 1 gives units of vitamin content in a pound of each type of feed and the cost per pound of the feed.

The mix must contain at least 12 units of vitamin A, 14 units of B, and 8 units of C. If x_1, x_2, x_3, and x_4 denote

TABLE 1

	A	B	C	Cost/lb.
F_1	4	1	0	2 cents
F_2	6	1	2	5 cents
F_3	1	7	1	6 cents
F_4	2	5	3	8 cents

the numbers of pounds respectively of F_1, F_2, F_3, and F_4, then the problem is to find non-negative values of x_1, x_2, x_3, x_4 which satisfy

$$\begin{cases} 4x_1 + 6x_2 + x_3 + 2x_4 \geq 12 \\ x_1 + x_2 + 7x_3 + 5x_4 \geq 14 \\ 2x_2 + x_3 + 3x_4 \geq 8 \end{cases} \qquad \text{Eq. 3.}$$

and which minimize the cost function

$$2x_1 + 5x_2 + 6x_3 + 8x_4 = z. \qquad \text{Eq. 4.}$$

The algebraic statements of these two problems, though similar, have distinct differences. In one, an objective function is to be maximized. In the other, the objective function is to be minimized. In one the inequalities are "less than" and in the other the inequalities are "greater than." Yet, with only a little juggling the algebraic statements of these two problems can be made the same.

To avoid the inequalities a "slack" variable can be added or subtracted from each inequality restraint. Normally, these slack variables have a physical meaning. For example, in the paper machine problem no more than 400

tons of grade 1 are to be produced; that is,

$$x_1 \leq 400.$$

This implies that there may be some unused tonnage and the quantity of this unused tonnage for the second restraint can be denoted by the slack variable x_4. Continuing in this manner for all inequalities of the first problem we get the following set of equations

$$\begin{cases} x_1 + 2x_2 + x_3 = 800 \\ x_1 + x_4 = 400 \\ x_2 + x_5 = 300. \end{cases} \quad \text{Eq. 5.}$$

where x_3, x_4, and x_5 are the slack variables for the first, second and third expressions respectively. Likewise, in the diet problem the minimum vitamin requirements may be exceeded, and this excess may be denoted by the non-negative slack variables x_5, x_6, x_7, all with a coefficient of -1, giving

$$\begin{cases} 4x_1 + 6x_2 + x_3 + 2x_4 - x_5 = 12 \\ x_1 + x_2 + 7x_3 + 5x_4 - x_6 = 14 \\ 6x_2 + x_3 + 3x_4 - x_7 = 8. \end{cases} \quad \text{Eq. 6.}$$

Thus, both types of inequalities may be "standardized" to equations through the introduction of slack variables. The simplex method can be applied only to a set of restraints which are in "standard" equation form.

The apparent conflict in the method of stating of the objective functions of the two examples can also be resolved quite easily. For example, if in the paper problem the profit function to be maximized is multiplied by -1, we then get

$$-20x_1 - 50x_2 = -p = z \quad \text{Eq. 7.}$$

The values of x_1 and x_2 which *minimize* this negative function, $z = -p$, will also *maximize* the corresponding positive function p. Therefore, every maximization problem can be converted to a minimization problem.

On the other hand, if the cost function of the diet problem is multiplied by -1 we have

$$-2x_1 - 5x_2 - 6x_3 - 8x_4 = -z = p.$$

The values of x_j which *maximize* this function will also *minimize* the original cost function Eq. 4.

Thus, minimization problems can be transformed to maximization problems, and vice versa. Obviously, computational rules for maximization problems are slightly different from those for minimization. Since most problems in practical applications of linear programming have the objective of finding the minimum of a linear function, such as cost, this paper will give rules for minimization.

Thus, we have standardized the general linear programming problem to one of finding non-negative values which satisfy a group of linear *equations* in several unknowns and which *minimize* a linear function. More formally, this can be written as follows: To find $x_1, x_2, \ldots, x_n$, all non-negative, which satisfy

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = b_2 \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = b_m \end{cases} \quad \text{Eq. 8.}$$

and which minimize the objective function

$$c_1x_1 + c_2x_2 + \cdots + c_nx_n = z \quad \text{Eq. 9.}$$

This is called the *standard form* of the linear programming model.

AN EXAMPLE TO ILLUSTRATE THE PROCEDURE

To illustrate the procedures of the simplex method, consider the following small fictitious example similar to that in (2). In this example we are to find non-negative values of x_1, x_2, x_3, x_4, x_5 which minimize z where

$$\begin{cases} 3x_1 + x_2 + 13x_3 + 9x_4 - 6x_5 = 24 \\ x_1 + x_2 + 5x_3 + x_4 - 2x_5 = 10 \end{cases} \quad \text{Eq. 10.}$$

$$2x_1 + 4x_2 - 8x_3 - x_4 + 5x_5 = z \quad \text{Eq. 11.}$$

The last equation, of course, is the cost function. It is evident that this problem is already in standard form. Thus, slack variables need not be introduced.

A PROPERTY OF THE OPTIMAL SOLUTION

There is one important property of solutions which will be stated but not proved here.[1] This property is

PROPERTY OF THE OPTIMAL SOLUTION: *If there exist non-negative solutions to the system of equations, then at most m variables of the solution which minimize the function are positive, the rest are set equal to zero.*

That is, in the optimal solution the number of variables which are positive is limited by the number of equations. In the example above, Eq. 10, the solution which minimizes z will involve no more than 2 positive variables since there are 2 equations. If we had 5 equations in 20 unknowns, then at most 5 variables could be positive in the optimal solution, the remaining 15 variables being equal to zero.

Thus, in our problem we can arbitrarily set 3 variables equal to zero and solve for the other two. Suppose we set x_3, x_4, and $x_5 = 0$. Then we are left with

$$\begin{cases} 3x_1 + x_2 = 24 \\ x_1 + x_2 = 10 \end{cases} \quad \text{Eq. 12.}$$

$$2x_1 + 4x_2 = z \quad \text{Eq. 13.}$$

The problem has now been reduced to one of finding the solution of two equations in two unknowns, Eq. 12. Any standard method of elementary algebra may be used to solve these two equations. Ninth grade algebra students learn about substitution, elimination, etc. Consider the

[1] A rigorous proof of a more complete statement of this theorem can be found in (6, p. 75), and will be detailed quite extensively in (5).

method of elimination resulting from subtracting both sides of second equation from both sides of the first, getting

$$\begin{cases} 2x_1 = 14 \\ x_1 + x_2 = 10. \end{cases} \qquad \text{Eq. 14.}$$

Then dividing the first equation by 2 gives

$$\begin{cases} x_1 = 7 \\ x_1 + x_2 = 10. \end{cases} \qquad \text{Eq. 15.}$$

From this it is apparent that a partial solution of the system is $x_1 = 7$. To find x_2 this value of x_1 can be substituted into the second equation of Eq. 15. giving $x_2 = 3$. Another way to find x_2 is to subtract the first equation of Eq. 15. from the second,

$$\begin{cases} x_1 = 7 \\ x_2 = 3, \end{cases} \qquad \text{Eq. 16.}$$

which gives the same answer. Thus, through elimination the equations have taken on a new equivalent form, Eq. 16., which gives the answer immediately. These values of x_1 and x_2 may now be substituted into the cost function, getting

$$(2 \times 7) + (4 \times 3) = 26. \qquad \text{Eq. 17.}$$

That is, the cost associated with this first solution is 26 units of money (e.g., cents, dollars, etc.). This may be the solution which minimizes the cost, or it may not be. By trial and error we could go through all possible combinations of solutions of two variables. For each solution the value of z can be computed. Then that solution of non-negative variables which gives the smallest z will be chosen as the optimal solution.

The total possible number of solutions to be examined in this problem is the combination of five things taken two at a time, or ten solutions. By trial and error each of these ten possibilities can be determined and the value of z found without too much difficulty. However, for larger problems the trial and error procedures become prohibitive. For example, a system of 5 equations in 50 unknowns may require the examination of up to 2,118,760 combinations.

THE CANONICAL FORM OF THE LINEAR PROGRAMMING PROBLEM

Fortunately, there is a systematic way of finding in a much smaller number of steps that solution which minimizes the cost function. We begin in almost the same way as in Eq. 14., Eq. 15. and Eq. 16., except this time do not set x_3, x_4 and x_5 equal to zero quite so soon. Beginning with Eq. 10. let us do the same thing we did to get Eq. 14., namely subtract the second equation from the first. At the same time let us eliminate x_2 from the z function by multiplying the second equation by 4 and subtracting from both sides of the cost function. This gives

$$\begin{cases} 2x_1 + 8x_3 + 8x_4 - 4x_5 = 14 \\ x_1 + x_2 + 5x_3 + x_4 - 2x_5 = 10 \end{cases} \qquad \text{Eq. 18.}$$

$$-2x_1 - 28x_3 - 5x_4 + 13x_5 = z - 40 \qquad \text{Eq. 19.}$$

Now both sides of the first equation can be divided by 2, getting

$$\begin{cases} x_1 + 4x_3 + 4x_4 - 2x_5 = 7 \\ x_1 + x_2 + 5x_3 + x_4 - 2x_5 = 10 \end{cases} \qquad \text{Eq. 20.}$$

$$-2x_1 - 28x_3 - 5x_4 + 13x_5 = z - 40 \qquad \text{Eq. 21.}$$

As with the transition from Eq. 15. to Eq. 16. let us now eliminate x_1 from the second equation of Eq. 20. and from the cost function Eq. 21. This can be accomplished by subtracting the first equation from the second and by adding 2 times the first to the cost function. This gives

$$\begin{cases} x_1 + 4x_3 + 4x_4 - 2x_5 = 7 \\ x_2 + x_3 - 3x_4 = 3 \end{cases} \qquad \text{Eq. 22.}$$

$$-20x_3 + 3x_4 + 9x_5 = z - 26 \qquad \text{Eq. 23.}$$

This is called the *canonical form* of the linear programming problem. The coefficients in the cost function of the canonical form are called *relative cost factors.*

Note that through elementary algebraic operations the coefficient of x_1 has been made equal to $+1$ in the first equation of the canonical form, zero in the second equation, and zero in the cost function. Likewise, the coefficient of x_2 is $+1$ in the second equation and zero elsewhere. Furthermore, the coefficients of the remaining variables and the values of the constant terms are not the same as they were in the original problem, since the elementary algebraic operations are applied to all variables in each equation.

Now we can set x_3, x_4, x_5 equal to zero in both equations and the cost function. The solution is easily seen to be

$$x_1 = 7, \quad x_2 = 3, \quad x_3 = 0, \quad x_4 = 0, \quad x_5 = 0$$

and

$$z = 26$$

This is exactly the same solution we found before. The variables which are not set equal to zero—in this case x_1 and x_2—are called *basic variables.*

Let us recapitulate for the general problem. We began with the *standard form* given by Eq. 10. and Eq. 11., and through elementary algebraic operations arrived at the *canonical form* of Eq. 22. and Eq. 23. relative to the basic variables x_1 and x_2. Since similar operations can be performed on any algebraic system of linear equations, we can reduce through elementary algebraic operations the general standard form of the linear programming problem of Eq. 8. and Eq. 9. to the following equivalent form:

$$\begin{cases} x_1 + \bar{a}_{1,m+1}x_{m+1} + \cdots + \bar{a}_{1n}x_n = \bar{b}_1 \\ x_2 + \bar{a}_{2,m+1}x_{m+1} + \cdots + \bar{a}_{2n}x_n = \bar{b}_2 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ x_m + \bar{a}_{n,m+1}x_{m+1} + \cdots + \bar{a}_{mn}x_n = \bar{b}_m \end{cases} \qquad \text{Eq. 24.}$$

$$\bar{c}_{m+1}x_{m+1} + \cdots + \bar{c}_n x_n = z - z_0 \quad \text{Eq. 25.}$$

This is the *canonical form* of the general linear programming model relative to the basic variables $x_1, x_2, \ldots, x_m$.

A distinguishing characteristic of the canonical form is apparent. In each equation the coefficient of one of the variables is made equal to $+1$. The coefficients of this same variable in the remaining equations and also the objective function are made equal to zero. Since only one variable from each equation is forced to have a coefficient of $+1$, the number of variables which have this characteristic will be equal, except in certain cases, to the number of equations. These m variables are called the *basic variables.*

Since the algebraic operations required to reduce the system to canonical form must be applied to all variables in each equation, it is evident that the constant terms and the coefficients of the remaining, non-basic variables cannot be the same as they were in the original problem. To distinguish these new numerical values, we use the same letters as before but put a bar over them; i.e., $\bar{a}$, $\bar{b}$, and $\bar{c}$.

It should not be concluded that the basic variables of the canonical form are restricted to the first m variables. Any combination of m variables may constitute a set of basic variables. The combination and the order given in the system of Eq. 24. and Eq. 25. is merely a convenient general way of expressing the canonical form.

One caution should be noted: the basic variables should be chosen in such a way as to make all constant terms, $\bar{b}$, non-negative. The reason for this and methods for insuring this will be apparent later.

An advantage of the canonical form is that one solution, namely,

$$\begin{aligned} x_1 &= \bar{b}_1 \\ x_2 &= \bar{b}_2 \\ &\vdots \\ x_m &= \bar{b}_m \end{aligned}$$

$$x_{m+1} = x_{m+2} = \cdots = x_n = 0$$

which has a cost $z = z_0$, can be found readily. Thus, from the canonical form it is easy to state a solution in which at most m variables are positive, the rest being set equal to zero. Another more important advantage is set forth in the next section.

TEST FOR OPTIMALITY

The major advantage of the canonical form is that the non-basic variables can be inspected *relative* to the basic variables. For example, the coefficient of x_3 in the cost function, Eq. 23., of the canonical form is equal to -20. If x_3 were permitted to be some positive quantity, keeping x_4 and x_5 zero, the value of z will be reduced. In fact, z will be reduced by 20 units of money for each integral valued increase in x_3.

Thus, when the linear programming problem is in canonical form, a test for optimality is the following: *A solution is optimal if all relative cost factors, $\bar{c}_j$, are non-negative. If any relative cost value is negative, the solution is not optimal and can be improved by setting one of the corresponding variables equal to some positive value.*

Since $\bar{c}_3$ is -20 in the canonical form of the example, the solution is not optimal. A new solution, in which $x_3 > 0$, will reduce the cost. A method of finding this new solution is given in the next section.

IMPROVING AN NON-OPTIMAL SOLUTION

Since we want to minimize z, it seems reasonable to increase x_3 as much as possible. However, we are restricted by Eq. 22. from increasing x_3 without bounds. In fact the largest possible value of x_3 is found from writing Eq. 22. without variables x_4 and x_5. These need not clutter up the analysis since they are to remain equal to zero. Thus we get

$$\begin{cases} x_1 = 7 - 4x_3 \\ x_2 = 3 - x_3 \end{cases}$$

From the first of these we see that x_3 can be as large as $7/4$, or 1.75, and still permit x_1 to be non-negative. From the second the maximum value of x_3 is 3. If x_3 were permitted to be 3, then x_2 would be reduced to zero, but x_1 would become negative. Since negative results are not admissible in linear programming, we choose the value of $7/4$ for x_3. With this value of x_3, it is evident that $x_1 = 0$ and x_2 becomes $5/4$. Then, the new solution is

$$x_2 = 5/4, \quad x_3 = 7/4, \quad x_1 = 0, \quad x_4 = 0, \quad x_5 = 0$$

With this solution the cost becomes

$$z = 26 - 20x_3 = 26 - 20(7/4) = -9$$

which is a significant reduction from the cost value of 26 of the previous solution.

Thus, a new solution has been found with the basic variables of x_2 and x_3. This solution has reduced the cost function. However, we have not determined if it is optimal. Our rule for optimality requires the problem to be stated in canonical form relative to x_2 and x_3. We could go back to the original problem of Eq. 10. and Eq. 11. and reduce this to canonical form relative to x_2 and x_3. However, the equations of Eq. 22. and Eq. 23. are equivalent to those of Eq. 10. and Eq. 11. and are already part way in the desired canonical form, since the coefficient of x_2 is one in the second restraint equation and zero elsewhere. Therefore, we need only to make the coefficient of x_3 equal to one in the first equation of Eq. 22. and zero elsewhere. To make this coefficient equal to one, multiply both sides of the first equation by $1/4$, getting

$$1/4x_1 + x_3 + x_4 - 1/2x_5 = 7/4 \quad \text{Eq. 26.}$$

Now, to get zeros elsewhere multiple the first equation by $-1/4$ and add to the second equation of Eq. 22., and multiply by $+5$ and add to the relative cost function Eq. 23., getting the new canonical form of

$$\begin{cases} 1/4x_1 + x_3 + x_4 - 1/2x_5 = 7/4 \\ -1/4x_1 + x_2 - 4x_4 + 1/2x_5 = 5/4 \end{cases} \quad \text{Eq. 27.}$$

$$5x_1 + 23x_4 - x_5 = z + 9 \quad \text{Eq. 28.}$$

This is the canonical form relative to x_2 and x_3. Notice that the solution

$$x_3 = 7/4, \quad x_2 = 5/4, \quad x_1 = 0, \quad x_4 = 0, \quad x_5 = 0$$

with a cost value of $z = -9$ is readily found and is the same as was determined previously.

With the problem in canonical form relative to x_2 and x_3 we can now determine if this solution is optimal. The relative cost factors of Eq. 28 are all non-negative except for the coefficient of x_5. This implies that we still do not have an optimal solution, even though the cost was reduced from $+26$ to -9. However, another solution which will further reduce z can be found by permitting x_5 to be a positive value. The largest possible value for x_5 is evident from rewriting Eq. 27. (omitting all zero variables):

$$x_3 = 7/4 + 1/2x_5 \quad \text{Eq. 29.}$$

$$x_2 = 5/4 - 1/2x_5 \quad \text{Eq. 30.}$$

In the first equation the coefficient of x_5 is positive. Therefore, any positive value of x_5, however large, will give a non-negative value to x_3. It is possible to have all equations in this same form, permitting the new variable to increase indefinitely. This would imply that the original model was probably constructed improperly.

Fortunately, in our example at least one coefficient is negative, giving an upper bound to the value of x_5. As is evident from Eq. 30., this maximum value is $x_5 = 5/2$, which makes x_2 equal to zero. Thus, a new solution with at least x_1, x_2 and x_4 all equal to zero can be found.

Since the canonical form relative to x_3 and x_5 gives the new solution immediately and also a test for optimality for this new solution, it is reasonable for us to find this canonical form. Continuing with the same type of calculations of the preceding steps, the canonical form relative to x_3 and x_5 is found to be:

$$\begin{cases} x_2 + x_3 - 3x_4 = 3 \\ -1/2x_1 + 2x_2 - 8x_4 + x_5 = 5/2 \end{cases} \quad \text{Eq. 31.}$$

$$9/2x_1 + 2x_5 + 15x_4 = z + 23/2 \quad \text{Eq. 32.}$$

Here all relative cost values are non-negative. Thus the solution is optimal and the calculations are finished. This optimal solution is

$$x_3 = 3, \quad x_5 = 5/2, \quad x_1 = 0, \quad x_2 = 0, \quad x_4 = 0$$

which gives a minimum cost value of

$$z = -23/2$$

This evidently is a profit. No other solution will give a smaller cost (or greater profit) value.

FINDING THE FIRST SOLUTION: ARTIFICIAL VARIABLES

In the preceding sections it has been assumed that the initial canonical form in non-negative variables can be found rather readily. For example, we experienced no difficulty in finding the canonical form of Eq. 22. and Eq. 23. relative to the basic variables x_1 and x_2.

Unfortunately, such ease in finding the first solution is not characteristic of linear programming problems. Had we chosen x_1 and x_3 as basic variables instead of x_1 and x_2, keeping x_2, x_4, x_5 all equal to zero, we would have found no solution to the linear programming problem. Either x_1 or x_3 would be negative. In fact, of the ten possible combinations of basic variables in this example, only six will give feasible solutions.

Thus, it was by chance that we picked variables which did lead to an initial canonical form in non-negative variables. With larger problems we would experience increasing difficulty in finding the initial set of basic variables. Therefore, a formal procedure for finding the initial canonical form is needed.

Many models of problems encountered in practice are often stated initially in canonical form. For example, the model of the paper making process was

$$\begin{cases} x_1 + 2x_2 + x_3 = 300 \\ x_1 + x_4 = 400 \\ x_2 + x_5 = 300 \end{cases} \quad \text{Eq. 33.}$$

$$-20x_1 - 50x_2 = z \quad \text{Eq. 34.}$$

This is already in canonical form relative to the slack variables x_3, x_4 and x_5. Thus, the simplex method could be applied immediately and eventually a final optimal solution found, if one exists.

On the other hand the example on feed mixing does not have such an obvious set of basic variables. The slack variables have negative coefficients and therefore cannot be considered basic variables for a canonical form.

Furthermore, as Dantzig points out, in considering linear programming problems little or nothing may be known, mathematically, about the model (2). It may have redundancies, inconsistencies, or even impossible requirements.

Thus, it is clear that a general technique, which is free of any prior knowledge or assumptions regarding the system, is needed to find the first canonical form. Dantzig has suggested a simple device which uses the simplex method itself to provide (if such exists) a first canonical form (2). This series of operations, in which the simplex method is used to find the first canonical form, is called *Phase I* of the calculations. After the first canonical form is obtained, the usual steps may be followed to find the final optimal solution. This second series of computations is called *Phase II*.

The procedure for Phase I is as follows:

1. Arrange the original system of equations so that all constant terms, b_i, are positive or zero. If any b_i are negative, multiply both sides of the equation by minus one.

Our example, given by Eq. 10. and Eq. 11., was originally stated with positive b_i terms, and no alterations are needed.

2. Augment the system to include a basic set of "artificial" variables, $x_{n+1} \geq 0$, $x_{n+2} \geq 0$, $\cdots$, $x_{n+m} \geq 0$. In our numerical example we get

$$\begin{cases} 3x_1 + x_2 + 13x_3 + 9x_4 - 6x_5 + x_6 = 24 \\ x_1 + x_2 + 5x_3 + x_4 - 2x_5 + x_7 = 10 \end{cases} \quad \text{Eq. 35.}$$

Any solution of Eq. 35. in which x_6 and x_7 are both zero, is also a solution of the original system Eq. 10.

3. Define a new function

$$x_6 + x_7 = w \quad \text{Eq. 36.}$$

which is the sum of the artificial variables and is called the "infeasibility form." Then, using the simplex method find the values of $x_1, x_2, \cdots, x_7$ which satisfy the augmented system Eq. 35. and which minimizes w.

Although the problem defined by Eq. 35. and Eq. 36. is not in canonical form, it is easily transformed to canonical form by subtracting each equation of Eq. 35. from w, giving

$$\begin{cases} 3x_1 + x_2 + 13x_3 + 9x_4 - 6x_5 + x_6 = 24 \\ x_1 + x_2 + 5x_3 + x_4 - 2x_5 + x_7 = 10 \end{cases} \quad \text{Eq. 37.}$$

$$-4x_1 - 2x_2 - 18x_3 - 10x_4 + 8x_5 = w - 34 \quad \text{Eq. 38.}$$

This is now in canonical form and the simplex rules can be applied to find the solution which minimizes w.

4. If the minimum value of w is positive, then no feasible solution exists and the procedure is terminated.

On the other hand, if the minimum value of w is zero, then all artificial variables must be zero since w is defined as the sum of these non-negative variables Eq. 36. The basic solution at this step is therefore a solution of the original unaugmented system.

At this point Phase II of the simplex method is begun by:

1. Dropping from further consideration all non-basic variables whose relative cost factors for form w are strictly positive;
2. Replacing the linear form w by the linear form z, after first modifying z to conform to a canonical form relative to the basic variables of the last step of Phase I; and
3. Beginning the computation with simplex method.

To illustrate this consider the canonical form with artificial variables as given by Eq. 37. and Eq. 38. In Phase I, the function w is to be minimized. The initial solution

$$\begin{aligned} x_6 &= 24 \\ x_7 &= 10 \end{aligned} \quad \text{Eq. 39.}$$

will not minimize w since four of the relative "cost" values in Eq. 38. are negative. Of these negative relative cost values, that of x_3 is most negative. Therefore the next canonical form will include x_3 as a basic variable. Solving x_6 and x_7 in terms of x_3 gives

$$\begin{aligned} x_6 &= 24 - 13x_3 \\ x_7 &= 10 - 5x_3 \end{aligned} \quad \text{Eq. 40.}$$

Since 24/13 is smaller than $10/5 = 2$, x_6 goes to zero and the new canonical form relative to x_3 and x_7 can be found to be

$$\begin{cases} 3/13x_1 + 1/13x_2 + x_3 + 9/13x_4 - 6/13x_5 + 1/13x_6 = 4/13 \\ -2/13x_1 + 8/13x_2 - 32/13x_4 + 4/13x_5 - 5/13x_6 + x_7 = 10/13 \end{cases} \quad \text{Eq. 41.}$$

$$2/13x_1 - 8/13x_2 + 32/13x_4 - 4/13x_5 + 18/13x_6 = w - 10/13 \quad \text{Eq. 42.}$$

Choosing again the variable with the most negative relative cost value, the next canonical form is

$$\begin{cases} 1/4x_1 + x_3 + x_4 - 1/2x_5 + 1/8x_6 - 1/8x_7 = 7/4 \\ -1/4x_1 + x_2 - 4x_4 + 1/2x_5 - 5/8x_6 + 13/8x_7 = 5/4 \end{cases} \quad \text{Eq. 43.}$$

$$x_6 + x_7 = w \quad \text{Eq. 44.}$$

Since all relative cost values for the infeasibility form are non-negative the minimum value for w has been reached. This completes Phase I.

The solution at this point is $x_2 = 1/2$, $x_3 = 3/2$, $x_1 = x_4 = x_5 = x_6 = x_7 = 0$ which makes the minimum value of w equal to zero. Thus, a feasible solution exists and Phase II is begun.

Since x_6 and x_7 have positive relative cost values, they will be dropped. Also, the original cost function Eq. 11. is to replace w. However, the addition of Eq. 11. to the equations of Eq. 43. will not give a system in canonical form, since the cost factors of x_2 and x_3 are not zero. However, if the first equation of Eq. 43. is multiplied by 8 and the second by -4 and both of these added to the cost function, Eq. 11., the coefficients of x_2 and x_3 in the cost function disappear, giving (with variables x_6 and x_7 omitted):

$$\begin{cases} 1/4x_1 + x_3 + x_4 - 1/2x_5 = 7/4 \\ -1/4x_1 + x_2 - 4x_4 + 1/2x_5 = 5/4 \end{cases} \quad \text{Eq. 45.}$$

$$5x_1 + 23x_4 - x_5 = z + 9 \quad \text{Eq. 46.}$$

This is identical to Eq. 27. and Eq. 28. and thus the final solution of

$$x_3 = 3, \quad x_5 = 5/2, \quad x_1 = x_2 = x_4 = 0$$

with the minimum cost value of

$$z = -23/2$$

can be found readily.

As Dantzig (2) points out the device of using an infeasibility form and a system augmented by artificial variables has several important features that should be noted:

1. No assumptions are made regarding the original system; it

may be redundant, inconsistent, or not solvable in non-negative numbers.

2. No eliminations are required to obtain an initial solution in canonical form for Phase I.

3. The end product of Phase I is a basic feasible solution (if it exists) in canonical form ready to initiate Phase II.

4. If there exists a feasible solution to the original system, then this same solution satisfies the augmented system with the artificial variables set equal to zero, making $w=0$. Since w is the sum of non-negative variables, its smallest possible value is zero. Thus, if feasible solutions exist, w is zero and all artificial variables are zero. Also if the smallest value of w is positive, then no feasible solutions to the problem exist.

COOKBOOK RULES FOR THE SIMPLEX METHOD

Although the preceding sections outline a rathre simple explanation to the simplex calculations, it is often desirable to formulate the computational procedures into a set of rules. Dantzig (2) has outlined these rules rather well and they are given here with some modifications. It will be seen that these steps will merely repeat and summarize the operations of the preceding sections.

Step 1. Arrange the original system of equations as given by Eq. 8. so that all constant terms, b_i, are positive or zero by changing the signs on both sides of the appropriate equations.

Step 2. Augment the system of equations to include a basic set of artificial variables $x_{n+1}\geq 0$, $x_{n+2}\geq 0$, . . . , $x_{n+m}\geq 0$ so that

$$\begin{aligned}
a_{11}x_2 &+ a_{12}x_2 + \cdots + a_{1n}x_n + x_{n+1} &&= b_1\\
a_{21}x_1 &+ a_{22}x_2 + \cdots + a_{2n}x_n + x_{n+2} &&= b_2\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\
a_{m1}x_1 &+ a_{m2}x_2 + \cdots + a_{mn}x_n + x_{n+m} &&= b_m
\end{aligned}$$

where $x_j\geq 0$ for all j.

Step 3. Initiate Phase I of the calculations by

(a) adding the infeasibility form

$$w = x_{n+1} + x_{n+2} + \cdots + x_{n+m}$$

(b) eliminating the artificial variables from the feasibility form w to reduce the augmented system to canonical form.

Step 4. Examine the relative cost values.

(a) If all relative cost values are non-negative, minimum w has been reached. Then
1. if $w=0$, initiate Phase II with step 7,
2. if $w>0$, STOP. There is no feasible solution.

(b) If any relative cost value is negative, the value of w may be reduced by setting any one of the variables associated with a negative cost coefficient equal to some positive value. If there are two or more negative relative cost values, the choice of the variable is arbitrary. It is usually best to pick the minimum $\bar{c}_j$. Call this value $\bar{c}_s$ and the corresponding variable x_s.

Step 5. To find the value of x_s, solve for the basic variables in terms of x_s as follows

$$x_i = \bar{b}_i - \bar{a}_{is}x_s$$

for all basic variables. Ignore any equation with $\bar{a}_{is}\leq 0$, since it would not be a restriction on x_s. Find the largest possible value of x_s by setting all $x_i=0$. The following candidates for x_s are examined

$$x_s = \bar{b}_i/\bar{a}_{is}$$

The smallest of these is to be the new value of x_s. Call this

$$x_s = \bar{b}_r/\bar{a}_{rs}$$

The variable that becomes zero is called x_r.

Step 6. Reduce the problem to canonical form through elementary algebraic operations with x_s as one of the basic variables in place of x_r and return to step 4.

Step. 7. Initiate Phase II by

(a) dropping all variables whose relative cost values in min $w=0$ are positive,

(b) replacing w by z,

(c) eliminating the basic variables from the cost function z to reduce the system to canonical form.

Step 8. Examine the relative cost values, $\bar{c}_j$.

(a) If all relative cost values are non-negative, STOP. The optimal solution is found by setting the basic variables equal to the constant terms, $\bar{b}_i$, and all other variables equal to zero. The value of the objective function will be $z=z_0$.

(b) If any of the relative cost values are negative, the solution may be improved by permitting one of the corresponding variables to be some positive value. If there are two or more $\bar{c}_j<0$, the choice of the variable to be introduced into the solution is arbitrary. Usually it is best to pick the minimum of the negative $\bar{c}_j$. Call this value $\bar{c}_s$ and the corresponding variable x_s.

Step 9. To find the value of x_s, solve for the basic variables in terms of x_s by

$$x_i = \bar{b}_i - \bar{a}_{is}x_s$$

Ignore any $\bar{a}_{is}\leq 0$, since it will not restrict the value of x_s.

(a) If all $\bar{a}_{is}\leq 0$, there is no finite solution, and the procedure can be stopped. Usually this implies that the problem was not formulated properly, and the original model should be checked again.

(b) If any $\bar{a}_{is}>0$, then find the maximum value that x_s can take on. Essentially this implies that the corresponding x_i are set equal to zero and the following candidates for x_s are examined

$$x_s = \bar{b}_i/\bar{a}_{is}$$

The smallest of these is chosen as the new value of x_s. Call this $x_s=\bar{b}_r/\bar{a}_{rs}$. The corresponding variable that becomes zero is called x_r. The new values of the remaining variables are found from

$$x_i = \bar{b}_i - \bar{a}_{is}x_s.$$

Step 10. To test if this is an optimal solution, the problem must be reduced to canonical form again through elementary algebraic operations with the new variable, x_s,

TABLE 2

	Basic Solution		Variables							
	Symbol	Value	x_1	x_2	x_3	x_4	x_5	x_6	x_7	$\bar{b}_k/\bar{a}_{ks}$
Phase I	x_6	24	3	1	(13)	9	−6	1		24/13
	x_7	10	1	1	5	1	−2		1	2
	$-w$	−34	−4	−2	−18	−10	8			
	x_3	24/13	3/13	1/13	1	9/13	−6/13	1/13		24
	x_7	10/13	−2/13	(8/13)		−32/13	4/13	−5/13	1	5/4
	$-w$	−10/13	2/13	−8/13		32/13	−4/13	18/13		
Phase II	x_3	7/4	1/4		1	1	−1/2	1/8	−1/8	
	x_2	5/4	−1/4	1		−4	(1/2)	−5/8	13/8	5/2
	$-w$	0	0	0	0	0	0	1	1	
	$-z$	9	5			23	−1			
	x_3	3	1		1	−3				
	x_5	5/2	−1/2	2		−8	1			
	$-z$	23/2	9/2	2		15				

as one of the basic variables. Return now to Step 8.

It should be apparent that these rules merely formalize the computational procedures of the previous sections. Thus, these rules can be applied to any linear programming problem, including the example of Eq. 10. and Eq. 11. However, rather than illustrate the application of the rules to the example as it stands, let us look at a second method for carrying out the simplex calculations, namely the simplex tableau.

THE SIMPLEX TABLEAU

In the preceding sections the simplex method was presented and illustrated with a simple algebraic example. Since all operations were performed on the example as it was presented, the symbols x_i had to be carried along in each step. This can be tiresome and even lead to clerical errors. In this section a brief discussion of a convenient tabular form will be given.

Suppose we consider the system Eq. 37. and Eq. 38. which is augmented by artificial variables and reduced to canonical form. This may be set up in detached coefficient form as in the first section of Table 2. Note that the "value" column contains the numerical values of b_i, the body contains the a_{ij}, the last row the relative cost values. The b_i are also the values of the first solution, namely $x_6 = 20$, $x_7 = 8$. Notice that $-w$ (and later $-z$) are entered rather than $+w$ (and $+z$) because the value of w_0 (and z_0) is on the right hand side of all equations when the algebraic operations necessary to reduce the problem to canonical form are performed. The circles around some of the entries will be explained shortly.

According to Step 4 of the "Cookbook Rules," the relative cost values are to be examined. It can be seen that at least one is negative. Step 4(b) suggests that the variable associated with the minimum, -18, be chosen as x_s.

To find the maximum value of x_3 solve for the basic variables in terms of x_3 as outlined in Step 3. The candidates for x_3 are found by dividing the b values (in "value" column) by the corresponding coefficients of x_3 (in x_3 column). For convenience, a separate column on the far right is provided for these ratios. The smallest positive value of these ratios is 24/13, and is chosen as the new value of x_3.

To determine if this is the optimal solution for w, a new canonical form is to be found, as suggested by Step 6. The variable leaving the solution is x_6 and the variable entering is x_3. Thus, the circled value, $a_{13} = 13$, must be changed to $+1$ and the rest of the values in the third *column* are to be zero. To make the new value of $\bar{a}_{13}$ equal to one, divide all values in the first *row* by 13, and place the results in the first row of the second part of Table 2. To make the rest of the coefficients in the third column equal to zero, modify the remaining rows by multiplying each coefficient in the first row by the appropriate factor and subtracting from the corresponding values in the other rows, including the w-row. These operations complete the second part of Table 2 and form a system in canonical form relative to the basic variables x_3 and x_7, and Step 4 is again applied.

In the third part of Table 2, all relative cost factors are non-negative and minimum w is reached. Since this value of w is zero, Phase II is begun with Step 7. Variables 6 and 7 are ignored, z is reduced to canonical form relative to x_2 and x_3, and the relative cost values are examined. Steps 8, 9 and 10 are repeated until Step 8(a) is reached. This was reached in the first iteration of Phase II as indicated in Table 2. The optimal solution is

$$x_3 = 3, \quad x_5 = 5/2, \quad x_1 = x_2 = x_4 = 0$$

and

$$z = -23/2$$

This is the same solution that was found previously.

CONCLUSIONS

This paper presented an approach to simplex calculations which can be followed quite easily by one with no more mathematical training than high school basic algebra. Although this paper does not claim to be a complete rigorous presentation, the techniques outlined here are adequate for handling many common linear programming examples.

For special problems, such as degeneracy, for special techniques such as the simplex method with prices, transportation method and the Hungarian method and for a much more rigorous presentation of all aspects of linear programming the reader is referred to Dantzig (5).

It should be pointed out that this article was based largely on three excellent papers by Dantzig (2), (3) and (4). Although these papers are not generally available, this development will be found in great detail in (5).

REFERENCES

(1) Charnes, A., Cooper, W., and Henderson, A., *Introduction to Linear Programming*, John Wiley and Sons, 1951.

(2) Dantzig, G. B., *The Simplex Method*, RAND Report, P. 891.

(3) Dantzig, G. B., *The Central Mathematical Problem*, RAND Report, P. 892.

(4) Dantzig, G. B., *Formulating a Linear Programming Problem*, RAND Report, P. 893.

(5) Dantzig, G. B., *Linear Programming*. (A basic text to be published in the near future.)

(6) Dorfman, Robert, Samuelson, Paul H., and Solow, Robert M., *Linear Programming and Economic Analysis*, McGraw-Hill, 1958.

(7) Noble, Carl, "The Simplex Method for Solving Linear Programming Problems," *Industrial Quality Control*, March 1957, pp. 5–9.

The Industrial Engineer as Internal Consultant—How?

by **THOMAS H. MARTZLOFF**

McKinsey & Company, Inc., Management Consultants, San Francisco, California

DID YOU read Professor Bentley's article (1)? He would like "Industrial Engineers to be known as professional engineers who help management manage"—in areas outside those normally assigned as "industrial engineering" responsibility.

This is indeed a worthy objective. I agree with its potential usefulness and desirability, particularly in medium-sized and smaller companies. In most instances managers need, and many want, help. Competent consulting assistance from within the company is especially appropriate, for example, in such matters as wage and salary administration, personnel selection procedures, developing effective communications programs, and working out the economics of facilities rearrangement or expansion.

But the mere stating of this "internal consulting" objective immediately raises these rather pressing questions:

1. What is the nature of this need, and what caliber of assistance do managers seek to fill it?
2. How is the Industrial Engineer to prepare himself for such important responsibility?
3. When prepared, how is he to get the chance to perform as an internal consultant on management problems of the sort Professor Bentley describes?

It seems to me that any individual who aspires to Professor Bentley's goal is forced to seek out workable answers to these questions that fit his *own* particular situation. Even so, I believe there are general guidelines in this special area of personal development that should not be overlooked.

To this end, let me propose some answers to these questions I have raised. My thoughts are a product of professional interest and experience in working with industrial executives on executive development as well as other kinds of top management problems. Some things I have learned bear importantly on the issue at hand.

Those who ponder the transition from Industrial Engineer to "internal consultant" may find them helpful.

IS THERE A NEED?

Unless there is a demonstrated *need* for internal consulting advice, these questions and our goal are of only

academic interest. We would merely indulge in wishful thinking.

But my experience shows that a need probably *does* exist in most companies, whether or not it is openly recognized. Edwards R. Fish, Jr., tends to confirm this belief in his interesting discussion of the Industrial Engineer's role in small company management (2). As I have observed, the need stems from three fundamental conditions:

1. *Executives are always pressed for time.* Rarely can they afford the luxury of concentrating solely on solving one problem at a time. The more time consuming the problem, the greater their need for problem-solving help. They seek aid from those not saddled with administrative detail and day-to-day supervisory duties.

2. *Today's management problems are increasingly complex.* They require better facts for sound solution. New techniques are involved. Seat-of-the-pants decisions grow less and less acceptable as the art of management takes on greater refinement. Competition won't allow it. Handling and analyzing data and using modern management techniques call for new skills which managers often do not have. They look for experienced help in these matters.

3. *Executives want objectivity.* Problems that concern management often transcend departmental lines. Usually they are heavily flavored with personalities. These facts-of-life present built-in limitations to any executive who seeks to delegate problem-solving responsibility to his line supervision. The supervisor is likely to be extremely *subjective*, particularly where his own department or his own men are involved. Rightfully, he has an "axe to grind." Thus some other source is frequently necessary for *objective* problem solving.

These factors argue for management staff assistance. As time goes on, it appears likely that this need will receive even greater recognition. And, this trend augurs well for the would-be internal consultant.

REQUIREMENTS FOR THE INTERNAL CONSULTANT

But managers are looking for a *special* kind of man to do this job. Free time and familiarity with technique, alone, will seldom qualify an individual for internal consulting in the broader management sense.

What, then, *are* the qualifications of the candidate who is likely to thrive in the kind of role Professor Bentley depicts? My observations indicate that these attributes are likely to distinguish him from his fellow Industrial Engineers:

1. *Desire to consult.* An Industrial Engineer must *prefer* an advisory capacity. Some, who are otherwise qualified, do not. The man with the desire to achieve this sort of professional status will dedicate himself to this, rather than to the line management route to success.

2. *Ability to think.* The candidate for consulting will be able to think deeply and independently (not always, by the way, an essential ingredient for the industrial engineering specialist). But the requirement goes even further: he will show a propensity to initiate ideas and to do the kind of thinking that gets to the core of problems quickly.

Executives themselves usually demonstrate great skill in "coping with situations" in response to pressures of the moment.* Digging deeply takes more time and work; it takes imagination to find causes and seek basic solutions. Further, the successful internal consultant will cultivate his ability to think broadly as well as deeply, not in the grandiose sense, but to come up with the fresh approach, not cramped by convention or narrowness of view.

3. *Judgment.* There is no substitute for this element. It is made up of common sense; sensitivity to people and to situations; and a fine sense of timing. Good judgment begins where facts, figures, and traditional logic leave off. Executives generally have it; the Industrial Engineer who wishes to counsel on management questions must have it or acquire it, largely by keen perception and learning throughout his general maturing process.

There are two particular aspects of judgment which deserve special mention:

(a) *Distinguishing the important from the unimportant.* In the minds of most managers, tangible end results are important. Some Industrial Engineers, on the other hand, appear to be more concerned with methodology and technique than with getting an acceptable end result in the least amount of time. I recall an Industrial Engineer who made such a production out of the simplest assignment that his superior was downright reluctant even to discuss problems with him. This Industrial Engineer, for all his intelligence, could not, or would not act on partial information (which is sometimes the only kind available); he could not tolerate imprecision (a certain degree of which makes good economic sense); he would refuse to estimate answers or to render judgment decisions (which time pressure may demand). In short, this man had difficulty focusing on the end purpose of assignments he was asked to perform. He was too preoccupied by the means—the trappings surrounding the principal issues.

(b) *Maintaining a commercial or entrepreneurial sense.* Each private enterprise has a profit-making objective. Sales, financial and engineering, as well as manufacturing, efforts contribute to this common goal.

All management tools and improvement programs are nothing more than means to this end. Sometimes the hoped-for program of one department must be subordinated to the greater advantage of the total enterprise. The individual with a "commercial sense" understands the need for such "arbitrary" actions. He understands the essentials in how his company makes money.

I am familiar with a concern troubled with high manufacturing costs. The Industrial Engineer involved launched vigorously into a clever labor cost saving program. Later, it was pointed out that labor represented only 10 percent, an insignificant portion, of total product cost.

Another Industrial Engineer recommended an immediate expenditure of $1,000,000 for a new warehouse which would yield handsome materials handling cost savings. Only then did he learn that his company was not financially capable of such an investment.

These men not only lacked "commercial sense," but an appropriate sense of inquiry and timing as well.

4. *Tolerance toward reality.* Too often Industrial Engineers tend to be purists. They are likely to treat situations as though they were black or white, right or wrong. This orientation can lead to a childish, all-or-nothing attitude when dealing with other people.

But, as we well know, life is rarely so simple. The realistic internal consultant will project himself mentally into other men's shoes. Thus, he will force himself to visualize the intense pressures which ebb and flow around *all* men and inevitably shape their

* Dr. Lyman Bryson of Columbia University has done some excellent thinking in the area of executive-consultant relationships.

thinking and their actions. He will realize that graceful, intelligent compromise is often essential (and in no way "unprofessional") in getting constructive action on his recommendations.

5. *Attractive personality.* While I believe this requirement is frequently overemphasized, the internal consultant to management must at least be able to work smoothly with people throughout the company. He will encourage a cooperative spirit; he will not arouse antagonism. His personality, at minimum, will be acceptable to the people with whom he works. In my experience, ability to command respect for his proved ability and his mature viewpoint is likely to outweigh minor personality deficiencies.

6. *Ability to sell ideas.* The filing cabinets of American industry are full of good ideas and sound recommendations that were never put to work. And ideas must be sold before they can be implemented. Any consultant's effectiveness can be realistically appraised by examining his "batting average" for getting recommendations sold and acted upon.

The Industrial Engineer who fails regularly on this score should re-examine his potential for internal consulting work.

Problem solving is hard work. It takes initiative, perseverance, and a degree of optimism. The successful individual will not be easily discouraged as he pursues difficult and sometimes elusive objectives. In my judgment, thoughtful re-examination of these qualities will explain to a large degree why precious few Industrial Engineers have attained truly internal consultant status.

PREPARING TO MEET THE REQUIREMENTS

If these *are* the qualifications, how is a man to approach the task of acquiring them?

At the outset, let's recognize the importance of personal make-up and innate qualities in fitting *any* man for *any* job. Some have it. Some don't. Qualifying for an internal consulting role is no exception. Good character and good taste, adequate education, good mental equipment, self-confidence, and imagination are among the essentials. Other qualifications may be more easily cultivated by the individual.

Perhaps you are personally acquainted with Industrial Engineers who aspire to an internal consulting role. While dispensing advice about personal career development is a hazardous occupation at best, you may wish to offer a helpful tip or two. Here are a few suggestions of the sort you might wish to convey to them:

1. *Add to your formal education.* Enroll in courses outside the industrial engineering area. Expose yourself to personnel, accounting, sales and public relations subjects. In this way, broaden your perspective and develop an appreciation for the problems of those in other phases of industrial activity.

2. *Read avidly, but with a critical eye.* Dwell particularly on management philosophies, principles, and approaches. Naturally, be aware of management methods and techniques as well, but don't enslave yourself to the particular solutions others have developed. Your problems are likely to be different. (Carefully selected materials from professional periodicals have value as well as textbook information, but watch out for "gimmicks" which fail to come to grips with underlying issues.)

3. *Inquire about problems within your own company.* Plenty of problems surround you. Have lunch with the Controller's Assistant, the Salary Administrator, the Purchasing Agent, the Labor Relations Assistant. Ask questions. Display interest in their problems and possible solutions. Make it a practice to keep informed. Don't "expert" these problems—just learn what they are. In the process, you will become a more capable Industrial Engineer as well.

4. *Think about these problems.* What would you do if they were your problems? What are the really fundamental issues, stripped of surface manifestations? How have these problems been solved before? Where have solutions fallen short? Why? How would your suggestions help the *company as a whole* to be more successful? Short or long term?

5. *Volunteer for extra duty.* Gradually ask for greater responsibility when you believe you can handle it well. Volunteer for study groups or working committees outside your normal working channels. Assume added responsibility within your own department. Contribute ideas on problems you see around the plant, even though it's not required of you.

6. *Participate in professional associations.* Your local AIIE Chapter for example, needs active leadership. The problems you will face and the responsibilities you will shoulder as an officer afford valuable experience.

7. *Learn about the logic of people.* Traditional $x + y = z$ logic has always worked admirably well on problems concerned only with "things." But when people enter this equation, strange things happen. People respond to another kind of logic—the logic of people. It takes a shrewd eye and deep understanding to predict the actions of human beings. Yet management problems on which you expect to consult are replete with "people problems."

Study people's motivation and behavior carefully. They are important. The internal consultant needs to have them working for him, not against him.

Reflect on the things you have learned. Hold onto the fundamentals you discover and discard the chaff. Relate the interaction of people and departments, as you observe them, to one another. Draw your own lessons from these experiences. Thus, deepen your understanding and appreciation of the company's people, its problems and their underlying causes. In these ways, the dedicated Industrial Engineer can gain maturity and necessary perspective. His qualifications for an internal consulting role will grow as well.

GETTING THE CHANCE

Obviously the well-prepared Industrial Engineer doesn't fold his hands and wait for a chance to consult on broader management problems. He seeks it, instead. The process is gradual, of course. His first chance may grow out of committee work or come as a result of a suggestion he has made.

But the well-equipped man who has gained respect from his associates and his superiors over the years has nothing to worry about.

His advice and counsel will be *sought out by others.* And at this point his principal concern will change from "How can I earn the opportunity to do consulting work?" to "How can I resist the pressure to join the ranks of the line managers?"

REFERENCES

(1) Bentley, Wilson J., "The Internal Consulting Functions of the Industrial Engineer," *The Journal of Industrial Engineering,* July-August, 1957.

(2) Fish, Edwards R., Jr., "Button, Button, Who's Got the Button," *The Journal of Industrial Engineering,* November-December, 1957.

Increasing Utilization of the Cost-Quantity Relationship in Manufacturing

by **RENO R. COLE**

Visiting Professor of Engineering, University of California, Los Angeles

CURVES of the cost-quantity relationship in manufacturing, also known as learning curves, progress curves, cost improvement curves, and time reduction curves, came into general use in the airframe industry during World War II.

As usually understood, the theory of such curves states that as the total quantity of a product or model manufactured for the first time doubles, the direct labor cost of the $2n^{th}$ unit will be less than the direct labor cost of the n^{th} unit by some fixed percentage of the n^{th} unit cost. Several early studies in the airframe industry have indicated that for airframes this percentage is 80%. Thus, for example, if the labor cost for the 10^{th} unit is \$1000, the labor cost for the 20^{th} unit would be 80% of this or \$800 and for the 40^{th} unit \$640, etc.

This relationship has the function

$$y = ax^b \qquad \text{Eq. 1.}$$

where x is cumulative unit number
y is labor cost
a, b are parameters

For the 80% curve mentioned above, b has the value -0.322. The labor cost of the first unit is always equal to a.

The cost quantity relationship has also been defined by

$$\bar{Y} = ax^b \qquad \text{Eq. 2.}$$

where $\bar{Y}$ is average direct labor cost

a, b and x are the same as in Eq. 1.

The appearance of the curves when defined either way is shown in Figure 2. The relationship Eq. 1. is known as the unit curve, while the relationship Eq. 2. is known as the cumulative average curve. The parameters a and b will have the same value for either definition. Eq. 1. will be used in this discussion.

The relationship Eq. 1. or Eq. 2. is hyperbolic (Fig. 1) and conveniently gives a straight line when plotted on logarithmic scale (Fig. 2). The percentage figure referred to (80%) is termed the "slope" of the curve. (This definition of slope is different from the one used in mathematics.)

USEFULNESS OF THE TECHNIQUE

Results of the survey reported here indicate that planners in many industries outside the airframe industry are now beginning to realize that use of the cost-quantity relationship is of basic importance for rational planning during the early manufacturing or "learning" stages of a new product or model.

The conventional data and formulae used by engineers estimating factory requirements for new products or new models can only give labor requirements "at standard," that is, for production conditions which have reached a "steady state." This is the cost per unit which is substantially[1] reached at C_1 for the $n_1{}^{th}$ unit of Fig. 1.

If the parameters of the cost-quantity relationship curve can be estimated, however, a prediction of direct labor requirements during the "learning" phase can be made on a quantitative and objective basis. Since the ratio of other costs to direct labor costs is usually known,

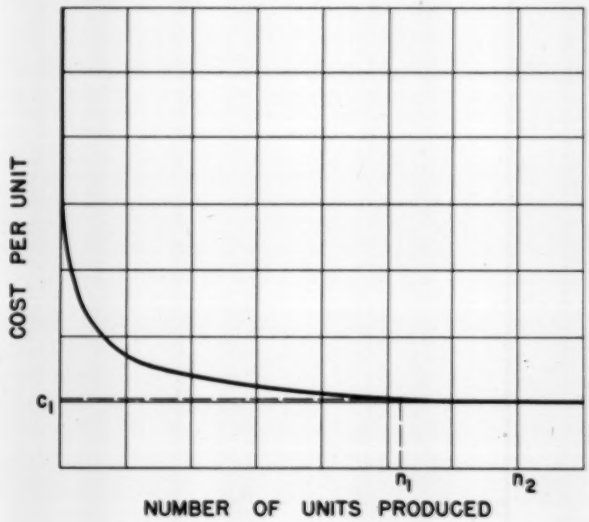

FIG. 1. Typical Cost-Quantity Curve

[1] Theoretically of course, if the relation Eq. 1. or Eq. 2. is assumed, the cost continues a very slow decrease indefinitely as production is continued.

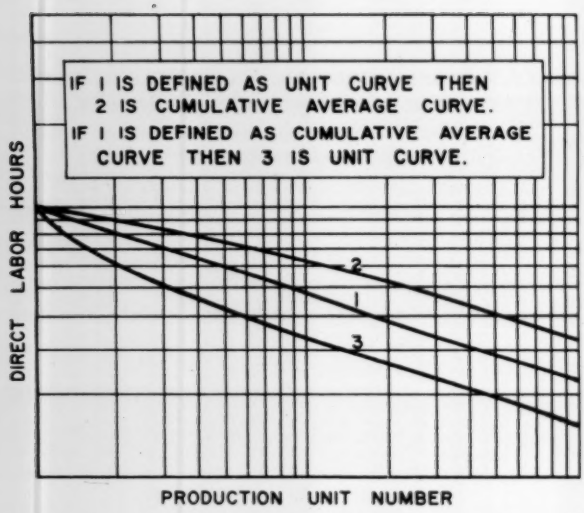

FIG. 2. Appearance of the Cost-Quantity Relationship Curve on Logarithmic Scale.

an accurate estimate of total production cost can therefore be made. In addition, scheduling of most of the requirements for the initial phases of production such as manpower, material, factory space, equipment, tooling, etc., can be put on a rational bases since requirements for these items are also related in a known way with direct labor usage (6).

In the case where the total number of units to be manufactured is limited, such as represented by the quantity n_2 (Fig. 1), the total cost which can be predicted, which is the area under the curve between n_1 and n_2, may well be small in comparison with the cost which cannot be predicted without use of the cost-quantity relationship. This the area under the curve between O units and n_1 units. The cost-quantity relationship thus also has an obvious and special importance in the pricing and general planning for products of limited total production quantity. Many defense contracts and some commercial products fall in this category.

HISTORY

From the historical standpoint, cost-quantity curves have been used in this country since about 1936, when a publication by T. P. Wright described the relationship and indicated its application in the airframe industry (16). The technique was used extensively in the airframe industry during World War II, and additional publications have appeared from time to time since the war. In addition to that of Wright, papers by Crawford (7), Berghell (2), Carr (4), Standford Research Institute (18), and others are of theoretical interest while airframe company publications of Glenn L. Martin Company (11), Chance Vaught Aircraft Incorporated (13), Northrop Aircraft Incorporated (12), North American Aviation Incorporated (3), and Boeing Airplane Company (19), were designed to assist in practical application of the principles. General descriptions of the technique and its applications have been published by Thue, Maynard and Shapell (15), Ghormley (8), Lundberg (10), and Cole (6). A recent publication by Asher (1) offers contributions to the theory and gives a comprehensive survey of present knowledge particularly pertaining to the airframe industry.

The cost-quantity relationship in manufacturing has been known and used for more than 20 years. In view of its importance it is, therefore, somewhat surprising that published literature on the subject is not more extensive. On investigation, this situation seems to result from the small amount of empirical data which has been made available for analysis. Most of the studies to date have been based on data from the airframe companies or from Air Force data obtained through airframe contracts. It is striking that with few exceptions (9) (14), no data or application studies have been published for any industry other than airframes.

SURVEY OF PRESENT USE

Since this study and other studies (9) (14) indicate that the cost-quantity relationship is as fully applicable and as useful in types of manufacturing other than the airframe industry, a survey of southern California industries was conducted to determine the extent of application of this technique in industries other than airframes.

Only non airframe metal product manufacturing industries having 300 or more employees were surveyed. Some results of the survey are given in Table 1.

CONCLUSIONS REGARDING PRESENT USE

Judging from the fact that 61% of the companies surveyed reported use of the cost-quantity relationship, this technique would seem to have found acceptance in industries other than airframe. It should be realized, however, that this tendency is probably more pronounced in Southern California than it is elsewhere due to the influence of the many airframe companies in this region in which this technique has been familiar for a number of years.

It is interesting that a high percentage of the companies surveyed who reported use of the technique considered it a necessary part of planning. A considerable percentage of replies were qualified, however, by stating that judgment was required in the use of the technique. This is, of course, true of the application of any Industrial Engineering technique, but the reply would seem to indicate the absence of a completely comfortable feeling on the part of many who use the cost-quantity concept. This is undoubtedly due to the limited amount of information available for industries other than airframe.

In (d), Table 1, is given a summary of cost-quantity

TABLE 1

Survey Results of Cost-Quantity Relationship Technique Utilization by Southern California metal product manufacturing industries other than airframe

(a) Do you use the cost-quantity relationship in your manufacturing planning?

	Number	Percent
Yes	28	61
No	18	39
Total	46	100

(b) Have you developed your own data or do you use published data?

	Number	Percent
Use own data	23	82
Use 80% airframe curve	5	18
Total	28	100

(c) What is your opinion as to the usefulness of this technique?

	Number	Percent
A necessity	7	25
Very useful	11	39
Useful but must be used with judgment	10	36
Total	28	100

(d) How is the cost-quantity relationship used in your operation?

	Number	Percent
Estimating	13	29
Pricing	11	24
Projecting manpower requirements	7	15
Projecting schedules	4	9
Used for standards	4	9
Facility analysis	2	4
Cost control	2	4
Budgetary control	2	4
Economic lot size	1	2
Total	46	100

relationship applications in the industries surveyed.

As might be expected, the greatest use is for estimating, pricing and projection of manpower requirements. Some of the minor uses mentioned are interesting and might profitably receive more attention by industrial planners. For instance, use of the cost-quantity relationship for planning economic lot sizes during the "learning" period was mentioned only once. However, the planning of lot sizes on a systematic basis during the learning period would seem to require application of the cost-quantity conception.

COST-QUANTITY DATA FOR INDUSTRIES OTHER THAN AIRFRAME

As there is an evident need for cost-quantity data which applies to industries other than airframe, a project was conducted at the University of California, Los Angeles, with the objective of collecting such data from typical industrial sources and subjecting it to suitable analysis. Due to security reasons, it proved unexpectedly difficult to obtain this type of information from industrial concerns. While not as complete a coverage of industries was achieved as hoped for, some interesting and, it is hoped, useful results were obtained which are reported in Table 2. Table 2 also lists all previously published data which could be found, with source references.

The parameters a and b were determined for the data collected in the present study by regression analysis using the least squares criterion and assuming the function given in Eq. 1.

CONCLUSIONS REGARDING COST-QUANTITY DATA PRESENTED

An examination of the data in Table 2 reveals a very small variance between the slopes obtained for the different types of manufacturing studied. While there is a range of 364 to 1,200,000 first unit hours, the range of slopes is only 77% to 82%.

The mean of the slopes given in Table 2 is 79.6%. Assuming random sampling and normal distribution, 95% confidence limits for the mean; computed using the t statistic, are 78.3% and 80.9% for this series of observations. At least, this result should be of some assistance to planners applying the cost-quantity relationship in a situation where the curve-parameters are as yet unknown.

Another conclusion which may tentatively be reached is that there is evidently no causal relationship between slope and first unit direct labor cost for different manufactured products. As mentioned below, such a relationship is now thought to exist, however between different models for airframes.

TABLE 2

Cost-Quantity Relationship Data from Various Industries

Product	Reference	First Unit "a" Hours	Slope, %
Precision mechanical electro-optical aircraft instrument	This study	2,175	78
Electronic unit; 80% electronic components, 20% mechanical components	This study	14,500	79
Mechanical-hydraulic electrical unit, 70% mechanical components, 30% electrical components	This study	364	77
Large built-up laminated plastic aircraft assemblies	This study	3,745	77
Electronic data processing equipment—Unit A	This study	987	82
Electronic data processing equipment—Unit B	This study	536	78
118 World War II airframe models	(17)	14.3*	79.7
Liberty ships—World War II composite experience of 10 yards	(14)	1,200,000 (Approx.)	81
Semi automatic machine tool	(9)	2,114†	82
Textile machine	(9)	3,200†	82
Multi-purpose construction machine	(9)	1,481†	80

* Hours per pound of airframe.
† Arbitrarily adjusted to conceal actual cost level.

PRESENT PROBLEMS REGARDING THE COST-QUANTITY RELATIONSHIP

Present problems concerning the cost-quantity relationship for manufacturing lie in two general areas: that of specifying a suitable curve, which means estimating the parameters a and b; and that of improving the curve, from a cost point of view, where the relationship has been established in a particular manufacturing situation.

SPECIFYING A SUITABLE CURVE

The first of these areas has received most of the attention given to the subject up to the present time. Certain principles have been tentatively established which are helpful in predicting a suitable curve. However, the practitioner interested in application of the technique is still faced with the necessity of making an estimate of slope based on data collected in his own operation or on the small amount of published data available. In addition, he must either estimate the cost of the first unit or estimate the number of units required before the curve will approach his estimated steady state production cost.

In making a decision regarding the slope, the estimator may be guided by two general relationships which seem to have been established in a preliminary way. The first of these states that the slope bears a direct relationship to the ratio of labor unaided by machine, such as assembly labor; to labor aided by machine, such as parts fabrication operations. This is to say that the curve will be steeper, and cost will decrease more rapidly, the greater the proportion of manual work to machine aided work involved (9). The other relationship has only been indicated for different models of the same product. This states that there is an inverse relationship between the percent slope as defined here and the labor cost of the first unit (1). This means that the higher the labor cost of the first unit of a new model of the same product, the lower will be the percent slope or the faster the cost will decrease with successive units of production.

Having made his best estimate of the probable slope, the planner is faced with the dilemma of either estimating the cost of the first unit or estimating the number of units required to attain substantially steady state operating costs. Unless he fells fairly certain of his estimate of the slope, and unless the relationship described above can be used as a guide, he may find it easier to estimate the quantity when steady production will be established, in view of the many uncertainties involved in estimating the unit number one cost. A comparison can, of course, be made using both of these methods. In any case, the problem facing the estimator is not a happy one and theory has not as yet made contributions which help him to any great extent.

The best answer to this part of the problem is careful collection and compilation of data under the existing manufacturing conditions. Unfortunately, many cost accounting systems are not adaptable to collection of learning curve data and managements are often not sufficiently aware of the plight of the estimator to be amenable to making revisions in the accounting system which would permit collection of the required information.

IMPROVING THE CURVE FROM A COST STANDPOINT

The other area of the cost-quantity relationship problem referred to above concerns the possible improvement, from a cost point of view, of a production situation where the cost-quantity relationship has already been established by experience. This possibility has received little recognition in the literature and the problem has evidently received little consideration. However, some present studies at the RAND Corporation represent a start in this direction (17).

Since the area under the cost-quantity curve represents the total cost, and since this area depends both on the number one unit cost and the slope, it is clear that any effort to improve a production situation from a cost standpoint during the "learning" phase be aimed at the number one cost as well as the slope of the curve. Indeed, as pointed out by Asher (1), a product having a steeper slope but a higher cost of the initial units may well have a higher average cost during the learning period than a product for which the reverse is true.

While the problem of reducing cost in steady state production conditions has been one of the major considerations of Industrial Engineering for many years, as mentioned above, the problem of reducing cost during the learning period has received little or no attention. It is to be noted that many defense products and a number of domestic products such as computers and possibly some airframes never get out of the learning phase before the contract is completed or a new model is introduced. While many of the techniques which have been developed to reduce cost in steady state manufacture are undoubtedly applicable to the learning stage, some of these techniques obviously have a different relative degree of effectiveness during this phase. There are undoubtedly new techniques waiting to be discovered and developed which are uniquely important during the learning phase. It seems that this area is a promising one for research.

REFERENCES

(1) Asher, Harold, *Cost-Quantity Relationships in the Airframe Industry*, The Rand Corporation, Publication R-291, July 1, 1956, 191 pages.

(2) Berghell, A. B., *Production Engineering in the Aircraft Industry*, McGraw-Hill Book Company, Inc., New York, 1944, Chapter 12.

(3) Blume, E. J. and Peitzke, D., *Purchasing with the Learning Curve*, North American Aviation, Inc., Inglewood, California, August, 1953.

(4) Carr, G. W., "Peacetime Cost Estimating Requires New

Learning Curves," *Aviation*, Vol. 45, April, 1946, p. 76-77.
(5) Chapman, Robert L., and Kennedy, John L., "The Background and Implications of the Systems Research Laboratory Studies," *Airforce Human Engineering Personnel Training and Research, Air Research and Development Command, Technical Report 56-6*, 1956.
(6) Cole, Reno R., "Got A New Product Idea?", *American Machinist*, December 5, 1955.
(7) Crawford, J. R., *Estimating, Budgeting and Scheduling*, Lockheed Aircraft Corporation, Burbank, California, 1944.
(8) Ghormley, G. E., "The Learning Curve," *Western Industry*, September, October, December, 1952, February, 1953.
(9) Hirsch, W. Z., "Manufacturing Process Functions," *The Review of Economics and Statistics*, Vol. 34, May 1952, p. 143-155.
(10) Lundberg, R. H., "The Learning Curve Theory as Applied to Production Costs," *S.A.E. Journal*, May, 1956, p. 48.
(11) Morgan, A. W., *Experience Curves Applicable to the Aircraft Industry*, The Glenn L. Martin Company, Baltimore, Maryland, 1952.
(12) Rayborg, W. A., *Mechanics of the Learning Curve*, Northrop Aircraft, Inc., Hawthorne, California, March, 1952.
(13) Rutan, E. A., *Theory of Learning Curves*, Chance Vought Aircraft, Inc., Dallas, Texas, October, 1948.
(14) Searle, A. D., "Productivity in Selected Wartime Ship Building Programs," *Monthly Labor Review*, Vol. 61, No. 6, December, 1945, p. 1132.
(15) Thue, H. W., Maynard, B. I., and Shappell, N. H., "Time Reduction Curves," *Proceedings 5th Annual Industrial Engineering Institute*, University of California, January 30-31, 1953, p. 27-34.
(16) Wright, T. P., "Factors Affecting the Cost of Airframes," *Journal of The Aeronautical Sciences*, Vol. 3, February, 1936, p. 122-128.
(17) *Crawford-Strauss Study*, Air Materiel Command, Dayton, Ohio, 1947, Chapter 4.
(18) Stanford Research Institute, "Relationships for Determining the Optimum Expansibility of the Elements of a Peacetime Aircraft Procurement Program," USAF, December 31, 1949.
(19) *The Expecience Curve and Improvement Curve Study*, Boeing Airplane Company, Wichita, Kansas.

System Simulation—A Fundamental Tool for Industrial Engineering

by **DONALD G. MALCOLM**

Director of Operations Research, Booz, Allen & Hamilton, Chicago

DURING recent years a new technique has come into prominence as an aid in both the task of training and in problem solving. This technique, called *System Simulation*, has been developed in both the military and industry by operations research and Industrial Engineering groups charged with making recommendations concerning complex planning problems and in developing training methods. A growing need for this thorough and scientific study, plus the availability of high speed electronic computers, has brought the concept of system simulation to the fore as a most useful Industrial Engineering and management tool.

System simulation has the most useful property of permitting experimentation with and testing of certain policy, procedure and organization changes in much the same way as the aeronautical engineer tests his design ideas in the laboratory or the "wind tunnel." Simulation, long used as an engineering method (11), is now being used to:

1. Study complex operating plans, and management controlling systems for the purpose of designing better plans and/or systems.
2. Study and train people in the operation of complex tasks.
3. Gain acceptance of proposed changes through better understanding of how a given system works or operates.

Simulation has application from very small day-to-day problems to complex management and industrial engineering problems requiring operations research teams and computers. As we shall see, simulation has the advantage of being easily understood, of being relatively free of mathematics and of often being quite superior to mathematical methods which may be too complex to apply or even not available. Another distinct advantage lies in the fact that simulation generally eliminates the need for costly trial and error methods of trying out a new operating concept on the real flesh and blood and machines.

The purpose of this paper is to develop in a non-technical manner answers to the questions, What? and How?, Who? and Why?, facing the Industrial Engineer interested in what simulation may offer. Discussion is therefore directed to the following objectives.

1. To indicate the nature and utility of the method by means of an illustrative example.
2. To describe some industrial applications of simulation and to provide a partial bibliography.
3. To relate the method to more analytical approaches and discuss its role in "Installation Theory."[1]

One of the difficulties involved in the solution of problems of the broad nature referred to, is the compartment-

[1] Installation Theory has been defined as "study of the over-all most efficient way of introducing a change" (17).

alized thinking that organization structure and accounting methods tend to impose upon the managers of the affected departments. Each manager is motivated primarily by goals related to his own function which generally conflict with cost goals in other departments. The management of inventory is a well-known example of this class of problems.

In solving such problems top management generally arrives at a solution by compromise—a little bit for everyone and really not getting the best economic solution from the over-all company point-of-view. Since this is a well-known problem, let us briefly discuss the question it raises. How can we get at such problems where interactions between various elements of the problem or between various functions in the organization play such an important role in finding this best over-all solution, and, perhaps even more important, getting the solution accepted and implemented?

METHODS FOR ATTACKING SUCH PROBLEMS

There are three general courses of action open to us which are of value in different ways.[2] Let us list these and then discuss each method briefly.

1. Experiment with the real facilities, machines and men.
2. Formal mathematical analysis—construct equations describing the various alternatives.
3. Conduct simulated experiments, or *System Simulation* as herein termed.

EXPERIMENT WITH THE REAL FACILITIES, MACHINES AND MEN

Generally speaking, any idea that has been thoroughly studied is still not proven until it is tried out in the real situation. In using this method, suggested ideas or plans are brought forward for consideration as a result of cost studies of varying degrees of detail and refinement. Or, we may decide to emulate the practices of successful competitors and plan to do better through knowledge of their successes and mistakes.

In either event the basic task of study and analysis of the interactions involved by means of "models" is not performed. The suggested plan, when approved, is simply put into effect. If the plan proves to be inadequate a modification is made. Thus, as often happens, we end up "experimenting" with our own men, machines and facilities. While in many cases this is the only method available—*and it does get action*—there is the attendant confusion and cost of operating inefficiently for a long period of time while "testing" alternatives that may be avoided by the analysis or simulation approaches.

FORMAL MATHEMATICAL ANALYSIS

This is the most desirable and powerful approach. However, this method, which may be said to consist of writing equations which describe completely the problem area or system under study, is often too complicated to utilize effectively. Also in many situations the mathematics have not or cannot be developed which will permit all the desired factors to be considered simultaneously. This is particularly true in the case of competitive problems (4).

Further, the mathematical method generally poses a distinct problem in communication. It is often hard to convince people that what a complex formula seems to say is really the best thing to do. There are many "if's" and "but's" that are hard to overcome in the process of getting change accepted. Thus "experimentation," as discussed above, generally still has to be performed. In cases where the first two methods have not given satisfactory results the method of *System Simulation* is often useful.

SIMULATED EXPERIMENTS—SYSTEM SIMULATION

In using this method the problem or system under study is first described as the sequence of individual operations to be performed. This may be called the "Flow Model" of the system. It is then necessary to have data indicating how the individual operations are interrelated and to have the frequency distribution of elapsed times for each individual operation for the different conditions to be explored.

Then inputs of such items as manpower, scheduling methods, or amounts of equipment, facilities, etc. are systematically varied. By consulting the time data mentioned above in a random manner, the over-all time for the sequence of operations can be determined. This process performed over and over simulates operation of the system and permits accruing such total system data as average equipment and manpower utilization, or inventory outages, delays etc. Such outputs are then used to evaluate the desirability of the given input under test and in effect a simulated experiment has thus been conducted.

AN ILLUSTRATIVE EXAMPLE

Since the foregoing description is somewhat brief, a relatively simple yet practical example will be traced through to illustrate the concept and provide a vehicle for further discussion of the method and some applications that have been made in industry. This particular example has also been chosen to bring out the relationship of the simulation method to the mathematical method for treating the same problem. For a solution of the same problem through queueing theory methods see reference (16).

THE PROBLEM STATED

Let us look at the following problem. We have a shop in which 20 machines run continuously for 24 hours per day 5 days per week. These machines experience breakdowns from time to time despite preventive maintenance

[2] L. M. K. Boelter has described various techniques of problem solution. See reference (5).

practices. We have four repairmen on duty at all times and the machines are such that only one repairman can work effectively at a machine at a given time. Further the repairmen cannot be used for other than the repair task at hand. As managers, we are concerned over two observable facts which have come to our attention.

1. From time to time we note that there are more than four machines down simultaneously and we wonder if a fifth repairman would be a profitable investment in labor to avoid machine waiting time.
2. We also note that there are many times when all repairmen are idle and that there are even more times when three and two repairmen respectively are idle. Therefore, we *also* wonder conversely, do we have *too* many repairmen and would not three repairmen be more satisfactory? Thus we have conflicting possibilities to study.

A ROUGH ANALYSIS—SOLUTION BY AVERAGES

Now suppose we have made studies which show that the average running time between breakdowns is ten hours and that on the average the necessary repairs require one hour to complete, i.e. the machine is down one hour out of every eleven total hours on the average.

This rough data indicates that from twenty machines we could expect 1/11 times 20 hours of work to arrive each hour. This turns out to be 1.82 hours of work arriving each hour and we have available 4 man-hours to take care of this work. This would seem to indicate (if we are content with this analysis) that 4 men could take care of the repairs quite adequately and with no machines ever caused to wait on a repairman. Further, we might expect to find on the average that repairmen are idle approximately 54 percent of the time $\left(\frac{4 - 1.82}{4} = .54\right)$.

However, recent work sampling studies made in observation of the actual workmen indicate that the percentage of idle man time actually varies from 32 to 63 percent and that machines wait for a repairman from 3.3 percent to 1.1 percent of the total available time. It is hard to pick out the best figures from the above utilization studies to use in our cost study. And further, how do we know what the effect of putting on or taking off an additional man would be?

A BETTER METHOD OF SOLUTION IS NECESSARY

Clearly, our rough analysis is not sufficient to evaluate the economics of utilizing another repairman. We could try to get an answer by experimenting with the real men and machines. To do this we would actually put on an additional man and after a period of time carefully measure how much better machine utilization we had achieved. Then if we weighted this against the cost incurred we could get a measure of improvement. Then, after awhile, we could cut back to three men and again measure the effects. While in effect this is the method we have been using, it is costly both in time and in money lost if we are not operating at the right solution now. As indicated, *System Simulation* is a way of performing this "experimenting" in the laboratory without the costly and disturbing job of experimenting with the real people and equipment (which are continually changing anyway).

PERFORMING THE SIMULATION WITH THREE REPAIRMEN

To perform this simulated experiment we need data which we already have from records concerning the running time between repairs and the elapsed time in making the necessary repairs. Our operations analyst tells us that we have a chance of one in ten (probability of .1 in mathematical language) of machine breaking down in any given hour of operations.[3] Further an extensive study of the resulting repairs discloses the following:

40% of the repairs require ½ hour to complete.
30% of the repairs require 1 hour to complete.
20% of the repairs require 1½ hours to complete.
10% of the repairs require 2 hours to complete.

These data tell us that we have a 40% chance of a given breakdown requiring ½ hour to repair, a 30% chance of it requiring an hour to repair, etc. With these data we are now ready to simulate what would happen if we were to use various numbers of repairmen. Let us start with *three*.

Our first task is to estimate how many machines will break down in a given hour of operation of our simulated

[3] A statistical analysis of the breakdowns is necessary to establish the appropriate probability statement. See reference (4).

TABLE OF RANDOM DIGITS 67

03300	87949	59115	26885	48261	76540	67250	69705	03936	27536	52568
03301	51343	98859	77231	10765	55295	34116	85842	97783	09346	90710
03302	21397	90842	30562	73877	98000	40627	50655	78125	48864	92845
03303	54696	95594	14946	57540	39628	54643	76085	86416	33326	89169
03304	53676	73107	27956	57494	20694	10757	86038	48807	58577	73570
03305	94874	80302	51391	61287	38416	15559	29084	00561	96030	74125
03306	78508	94303	87162	28094	47554	75403	48748	34074	88055	52322
03307	57623	65457	91297	51592	22052	84757	88940	58760	49212	66688
03308	01471	88847	22546	63509	90082	34417	27537	81276	78832	83479
03309	56630	31877	06048	64380	13625	26616	22899	65479	79981	20991

FIG. 1. Table of Random Digits (Reproduced with permission from "A Million Random Digits" by the Rand Corp., 1955, The Free Press, Glencoe, Ill.).

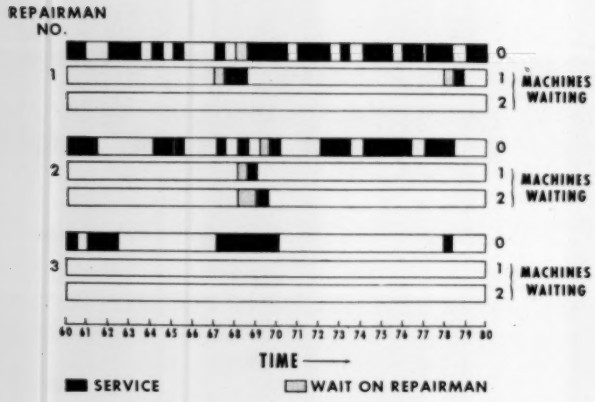

Fig. 2. Time Log of Breakdowns

system. To do this we could turn to a roulette wheel with ten numbers. It is quickly apparent why the term "Monte Carlo" method has become popular in describing an important aspect of *System Simulation.*

Since our chances of having a breakdown were previously determined to be one chance in ten we can let any one of the ten digits represent a breakdown. We are assuming an unbiased wheel wherein the ball is as likely to land on one number as any other. In our example we shall arbitrarily assign the number *9* to represent a breakdown.

Now, rather than actually use this exciting device of chance, let us refer to a table of random numbers that has been painstakingly recorded by scientists for just such types of analysis. This table may be thought of as the record of many throws at the wheel. It is an unbiased listing that gives us numbers that are perfectly random. Fig. 1 represents a portion from such a table of random numbers.

Since we have 20 machines, each with a chance for a breakdown, let us look at 20 numbers from this table as shown in the block at the left. In this group of 20 we observe that there are three number 9's. Thus three machines broke down during this hour. The next question is, "How long do these repairs take?"

To obtain this repair time we use the random number tables again. This time we assign digits 0-9 as follows:

Fig. 3. Time Log of Breakdowns

1-4 incl.	represent a ½ hour repair	(40%)
5-7 incl.	represent a 1 hour repair	(30%)
8-9 incl.	represent a 1½ hour repair	(20%)
0	represents a 2 hour repair	(10%)

Note that these are in the same proportion as our data concerning repairs as shown by the figures in parentheses.

Let us look at any three numbers to find out how long our three breakdowns require in repair. We shall use the last digit of each five digit number shown in the right inset. This gives us the 5, 8 and 4 shown underlined and our repairs will thus require 1, 1½, and ½ hours respectively. We have now *simulated* one hour of operation of our man-machine system and can keep score as shown in Fig. 2.

The same method is continued until many such hours are simulated, and results in building up the rest of the Fig. 2 as shown. As we go along we finally get into troublesome situations. In time period 68 for example, we found that more work arrived than we could conveniently handle with our work force. The waiting time that is necessary due to this "unlucky" work load is shown as a shaded bar. This represents time which the machine was down and could not be worked on because the repairmen were all occupied on other jobs that had arisen earlier.

One notes that there is a lot of idle man time and *still*

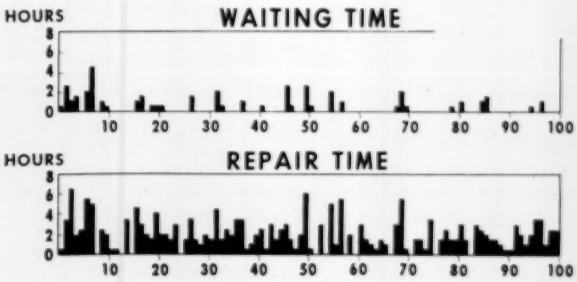

Fig. 4. Repair and Waiting Time Generated

a fair amount of required idle machine time. Fig. 3 shows another portion of the simulation in which a greater amount of work happened to arrive. That is—more 9's came up in our "throw of the dice."

In Fig. 4, graphical portrayal of the arrival of this work is shown at the bottom, and the top of the graph indicates when the waiting time occurred. This figure depicts 100 hours of *System Simulation.* At this point we have now simulated the operations of this greatly simplified management system in the laboratory. This has been done without disrupting the organization by removing or adding an employee and without waiting until working habits settle down so that a real live time study would produce meaningful data.

PERFORMING THE SIMULATION WITH 2, 4, AND 5 REPAIRMEN —DATA RESULTING

We next perform simulation for 2, 4, and 5 repairmen

TABLE 1

Data Reduction from Simulations	Number of Repairmen			
	2	3	4	5
Breakdowns per Hour, Ave.	1.78	1.95	1.97	1.97
Hours per Repair, Ave.	.994	.972	.970	.970
Machine Running Time—Percent	79.5	87.8	89.6	90.1
Idle Repairmen Time—Percent	13.5	36.7	52.0	61.6

in a similar manner. *Table 1* indicates the data summarized from these simulations.

Examination of these data indicates the gain in machine utilization through employment of additional repairmen. We note that there is a smaller increase in machine running time as additional repairmen are used. At this point our simulation is completed and we are in a position to put costs on the data in such a way as to make a lowest cost solution.

UTILIZING RESULTS OF SIMULATION IN MAKING A DECISION

While it is not our purpose to deal primarily with the economics involved in this illustrative example, perhaps one way in which the data can be used should be shown in the interest of making a complete example. Suppose in our example it is our intention to turn out a specific amount of production per week and that we will work on Saturdays, if necessary, in order to turn out this planned amount.

Suppose further that considering the overtime and standby labor involved, we have ascertained that idle machine time costs us $5.00/hour. Our regular repairman rate is $2.50/hour. Now with the data in Table 1 we can compute the cost per machine hour of operating with different numbers of repairmen.[4] Fig. 5 depicts the results of such computations.

In this case our decision is indicated quite clearly—we should change to three repairmen instead of the four currently used. From Fig. 5 we can also estimate the annual savings which turns out to be $4200 with the same total production possible. While this is a small amount, the relative size of the problem should be kept in mind.

MANAGEMENT PARTICIPATION IN EXPERIMENTATION

Let us carry this illustrative example a little further to indicate a very useful aspect of system simulation. At this point, the manager of the affected department may well have some ideas concerning how he could get better results than indicated by the simulation. This attitude should be encouraged. He might, for example, suggest that giving priority to certain of the repairs that arise during any hour could improve the machine utilization,

[4] C/machine hour $= \frac{r \cdot 2.50 + 5.00}{m} (1 - \%$ machine running time) where: r = number of repairmen, m = number of machines in group.

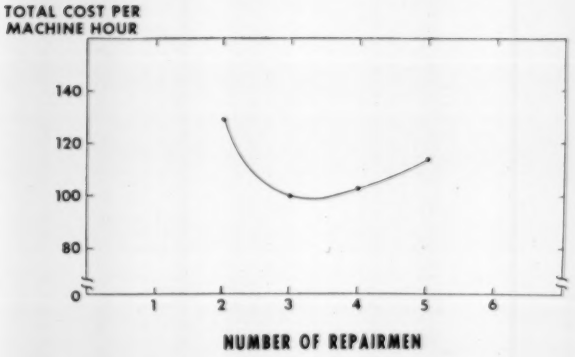

Fig. 5. Total Variable Cost per Machine Hour

or that purchase of more "reliable" machines would be a better course of action.

The *System Simulation* can easily be extended to permit this manager to try out these ideas. Indeed, this aspect of simulation, involvement of the affected party, is turning out to be one of its most powerful attributes, for such involvement enhances understanding and therefore acceptance.

PRIORITY VERSUS ARRIVAL SCHEDULING OF REPAIRS

In the simulation as originally performed the repairs were performed in the exact order in which they arrived. The manager has suggested that the shorter repairs should always be performed first when several breakdowns occur at the same time. This is referred to as "priority" scheduling.

To do this the simulation analyst must keep track of all the repairs arriving in any hour and assign them to be repaired in accordance with the priority rule of "assign the shortest repairs" first. Several other rules might have been suggested but let's consider the effect of this one by simulation. We perform the experiment in exactly the same manner except that we now apply the priority rule. When this has been completed for the various number of repairmen, we have data which are shown in Fig. 6.

We note that there is a slight gain in applying this priority rule. To evaluate the gain, we merely estimate

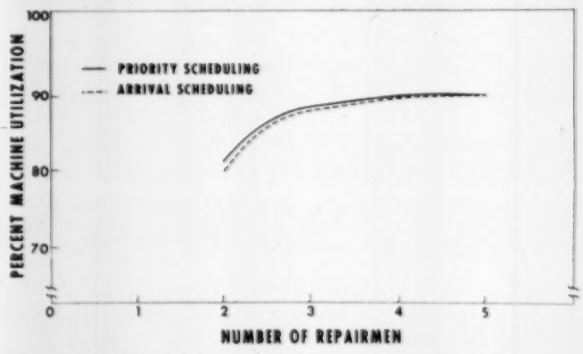

Fig. 6. Machine Utilization Priority Versus Arrival Scheduling

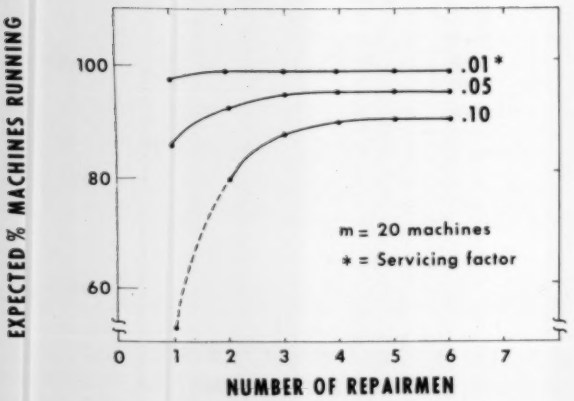

FIG. 7. The Effect of Using More Reliable Machines

the savings obtained versus the cost of having someone apply the scheduling required to obtain the savings. (It may not cost anything.) The manager is now in a position to evaluate how sophisticated a system he should employ in controlling his repair personnel.

THE EFFECT OF INTRODUCING MORE RELIABLE MACHINES

Without belaboring this example, we again perform the simulation in the same manner except that we alter the probability of breakdown in a given hour from .1 to .05 and to .01. This requires the use of two digit numbers from our table of random numbers to represent a breakdown. For example, we might let the numbers 00 to 04 represent the .05 probability of a breakdown. Otherwise the simulation is performed in exactly the same manner and results in developing operating curves such as shown in Fig. 7.

With this data we are in a position to evaluate the economics of purchasing more reliable machines. This example can also be thought of as being directly analogous to the loading or set-up time required in a job lot production shop. Here, repair time becomes set-up time. Thus we also have a method for evaluating the economies of more automatic machines.

THE ROLE OF THE COMPUTER

Up to this point the use of a computer in connection with the concept of simulation has not been mentioned. Generally speaking, most problems of any size worth exploring in any great detail will be most efficiently and economically handled through utilization of an appropriate electronic computer. The volume of detail and the number of hours that must be simulated in order to arrive at meaningful results generally demands that such a program be developed. In fact, even a problem of the size of the example, when extended to include the other conditions that we found desirable to make it more real, can be explored more efficiently and quickly if performed on an electronic computer.

In preparing the problem for the computer, the analyst generally prepares a logical Flow Diagram. This diagram shows the sequential steps involved in the problem or "system" under study. Fig. 8, prepared for the illustrative example, is typical of the kind of diagram that the analyst prepares in describing the system under study. This diagram is useful in the programming of the computer.

INDUSTRIAL APPLICATIONS

Perhaps the most dramatic aspects of system simulation lie in its ability to reproduce the workings of large scale systems. While such ambitious programs are of more interest, it should be borne in mind that their success is dependent on having performed many smaller simulations for experience, upon adequate data and upon consideration of the many mathematical and statistical problems that are involved in construction of a feasible and economical model. Those considering broad full scale models as panaceas in the decision making area are well advised to engage in smaller projects at the outset. This will prevent certain disillusionment and make for a more meaningful research program.

With this word of warning let us turn our discussion to a few industrial applications of system simulation. At a Symposium on System Simulation[5] the progress and results of several ambitious simulation projects were presented. Perhaps a listing of a few of these simulations discussed will serve to give an idea of their scope and content. We shall then turn to a brief discussion of a few examples.

Company or Organization for Which Simulation Was Designed	*Type of System Simulated*
United Air Lines	Airport Station Model
General Electric Company	1. Production Control Model 2. Profit Planning Simulation
Imperial Oil Limited	Distribution and Inventory Control Models
Port of New York Authority	Simulation of Peak Hour Bus Operations
Office of Naval Research	Simulation of Cargo Handling
Southern Pacific Railroad	Freight Car Inventory and Distribution
The Rand Corp.	1. Air Force System Training 2. Air Force Logistic System
ORO, The Johns Hopkins University	1. Army QM Requirements Forecasting Simulation 2. Army Bn Maintenance System Simulation
California Texas Oil Co., Ltd.	Decision Model—Caltex Group Operations
Thompson Products	Inventory Control Simulation
American Management Asso.	Top Management Decision Simulation

[5] Symposium on System Simulation, New York, May 16 and 17, 1957. Co-sponsored by the American Institute of Industrial Engineers, The Institute of Management Sciences and the Operations Research Society of America. See reference (31) for the report of this meeting and reference (1) for a brief review.

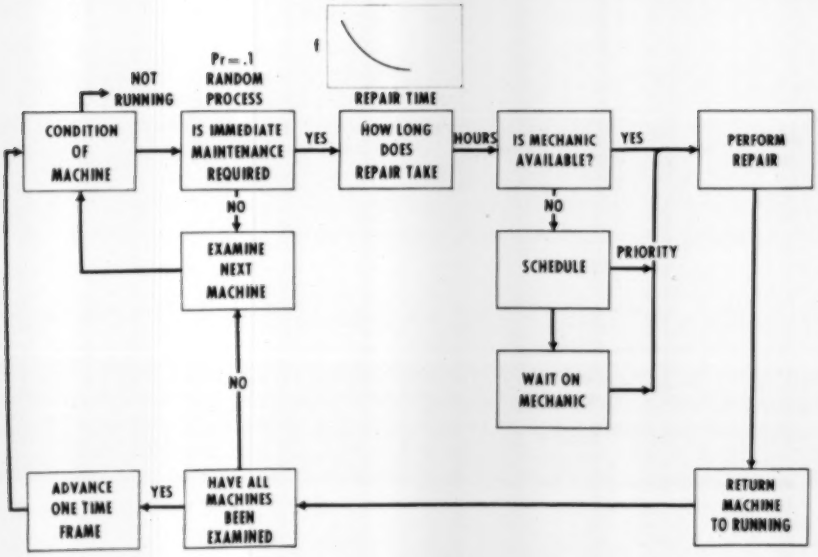

FIG. 8. Flow Diagram for System Simulation

In addition to the above, simulations of interest to Industrial Engineers have been performed at such companies as Eastman Kodak, Atlantic Refining, Matson Navigation Company, Monsanto, International Business Machines, etc. It is hoped that further symposia will bring out experiences of these companies.[6] Use of the technique has not yet jelled to the point where a common language has developed. However, a brief description of a few of the above simulations will set the stage for discussion of some common threads that appear to be present in the activities.

DISTRIBUTION AND INVENTORY CONTROL MODEL

Imperial Oil has studied an extensive distribution system composed of many hundred field warehouses in connection with an extensive expansion problem. The flow of stock under various possible combinations of facility plans was studied by simulation and costed. Results of this work were instrumental in suggesting a central warehousing method of operation (21).

Inventory and distribution problems are particularly complex and interrelated and are among the most important problems in management today. It is understandable, therefore, that we find considerable activity in the simulation of various distribution and inventory problems. Several papers presented at the symposium dealt with this problem area.

AIRPORT STATION MODEL

United Air Lines has set up and operated a simulation of the operations at a large airport on an IBM 704 computer (2). With it, several months of actual operations at an air terminal can be simulated in a matter of minutes. If one visualizes the "flow" of a plane through an airport and all the factors that determine the total time spent, such as landing, taxiing, maintenance, loading, etc., an idea of the complexity of the simulation is afforded. There are reportedly some 9,000 instructions in the computer program which took some nine months to develop after the logic was worked out in flow form. A diagram for this simulation, similar to Fig. 8, would be quite complex!

This model involved such structural and environmental elements as:

1. Time of day, week, and year
2. Weather conditions
3. Maintenance plan
4. Availability of spare aircraft
5. Manpower schedule

Probabilistic factors such as the need for maintenance, the type and length of resulting repairs, absenteeism of personnel and scheduling delays form the variable background for testing changes in company policies and practices. For example, management can change the number of spare aircraft, or the manpower schedule, and simulate operations under these new conditions. The computer is programmed to provide such output measures of performance as expected idle manpower, expected idle equipment, utilization of maintenance and berthing facilities. By comparing the expected performance in terms of these outputs with the cost of obtaining that perform-

[6] The Second System Simulation Symposium is scheduled for October, 1958.

ance, decisions can be reached that produce the best over-all operation of the complex airport system.

PRODUCTION CONTROL MODEL

The General Electric Company is using simulation to test new concepts and methods in production scheduling. Every production control manager knows that the methods priority rules and procedures that he uses in discharging his scheduling job have an important effect on his company's utilization of men and machines and also upon how smoothly the production flows and serves the customer.

In this model, factory operations are simulated to test these decision rules which, in effect, are the scheduling system. Policies and procedures concerning machine loading, scheduling, and dispatching are being systematically tested in the laboratory and evaluated in terms of internal inventory cost, idle man and machine time, flexibility and cost of the scheduling itself. In this way the trial and error method of actually trying out a new approach will be avoided. Rowe and Jackson have discussed this problem of research (22) (31).

PROFIT PLANNING SIMULATION

A television tube manufacturing company has explored ways of obtaining better profit from its over-all operations through simulation (19) (31). The flow of product was studied throughout the entire system. A flow chart of material from the point of purchase through operations in manufacturing to transportation in the distribution system was made. This chart served as the basis for programming a computer. Such factors as changes in volume imposed by the changes in customer demand, changes in product mix from a scheduling point of view, changes in the number and location of manufacturing plants, changes in the method and pattern of distribution and storage, and different expected losses of product in the manufacturing process could be made in the program put into the computer.

By studying these changes, it was possible to find out which factors were of the greatest sensitivity in producing profit and it was possible to experiment with possible changes in any of the factors indicated. Finally, the company feels that it has a realistic mechanism for planning and controlling its business system.

A TOP MANAGEMENT DECISION SIMULATION

The American Management Association has had constructed a "game" or "competitive simulation" built around the major control decision problem that a top executive faces in piloting the course of his company in a competitive economy (4) (21). This simulation exercise has been made the central subject of a two week course in Executive Decision-Making at Saranac Lake, N.Y.

In this exercise, executives must make decisions concerning the allocation of funds to production, marketing, research and development and new plant construction activities as well as set the price of their product and specify market research information to be procured and obsolete plant to be sold. These decisions must be made while in competition with four other companies, each striving for a greater return on their investment. The objective of this exercise is to give appreciation training to junior executives concerning the need for balance and the development of competitive strategies in plotting a company's course during ten years of simulated operations. Forms similar to the one shown in Fig. 9 are filled out every fifteen to twenty minutes (a quarter of a year's operation) and turned in for processing by an IBM 650 computer, which is programmed to determine the effect of their decision and print out the results.

Plotting of information, planning and budgeting activities and the critique session at the end of the play serve to bring out quite realistically many of the principles of scientific management.

COMMON THREADS IN THE USE OF SIMULATION

A survey of users of simulation gives us answers to two questions that are of interest. Why use simulation? —the purpose. Under what conditions is it used?—the type of problem.

The purposes may be summed up as follows:

1. To train people in their duties in a complex system.
2. To learn about the operation of a complex system. This may be for either research or training purposes.
3. To experiment with possible or suggested changes in policies, procedures, men, machines, under laboratory conditions and in a dynamic context.
4. To help develop a master plan for systematic management research leading to the development of new control systems.
5. To study the decision maker in a live situation.

The conditions under which simulation has been employed include the following:

1. Where uncertainty, or variability of data is an important factor and where direct mathematical methods are not available or practical to employ.
2. Where detailed procedures must be developed and alternatives can be evaluated only in terms of total system costs.
3. Where large, complex problems with many interrelated factors are to be studied and simpler models do not satisfactorily handle the interactions.
4. Where disagreement exists between affected parties in regard to proposed changes and an acceptable method of arbitration is required.

TRAINING THROUGH SIMULATION TECHNIQUES

In addition to the AMA simulation there are many other training simulations which have not been publicized as yet. Such companies as Westinghouse Electric Corporation, General Electric Co. and the Rand Corporation are using simulations, roughly equivalent in complexity to the illustrative example discussed earlier, to train their inventory people in problems of operating

STATEMENT OF ASSETS

YEAR 0 QUARTER 0

			TOTAL	NET CHANGE
CASH			$ 4,425,000	$25,000
INVENTORY	150,000 units @	$ 4.50	$ 675,000	$ 0
PLANT INVESTMENT	1,010,000 units @	$ 5.00	$ 5,050,000	$50,000
TOTAL ASSETS			$10,150,000	$75,000

ANNUAL STATEMENTS

YEAR 0

	COMPANY 1	COMPANY 2	COMPANY 3	COMPANY 4	COMPANY 5
CASH	$ 4,425,000	$ 4,425,000	$ 4,425,000	$ 4,425,000	$ 4,425,000
INVENTORY	$ 675,000	$ 675,000	$ 675,000	$ 675,000	$ 675,000
PLANT INVESTMENT	$ 5,050,000	$ 5,050,000	$ 5,050,000	$ 5,050,000	$ 5,050,000
TOTAL ASSETS	$10,150,000	$10,150,000	$10,150,000	$10,150,000	$10,150,000

INCOME STATEMENT

SALES INCOME	900,000 units @ $ 5.00		$4,500,000
COST OF GOODS SOLD & OPERATING EXPENSES			
COST OF GOODS SOLD		$4,050,000	
MARKETING & RESEARCH AND DEVELOPMENT		$ 300,000	
OTHER (MARKET RESEARCH)		$ 0	$4,350,000
			$ 150,000
OTHER INCOME (PLANT DISPOSAL)			$ 0
INCOME BEFORE TAXES			$ 150,000
TAXES			$ 75,000
NET INCOME			$ 75,000

MARKET INFORMATION

	COMPANY 1	COMPANY 2	COMPANY 3	COMPANY 4	COMPANY 5
PRICE	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
SHARE OF MARKET	20.00%	%	%	%	%
TOTAL MARKET	4,500,000				
POTENTIAL SALES	900,000				

MARKET RESEARCH REPORT

TOTAL INDUSTRY MARKETING EXPENDITURE	$
TOTAL INDUSTRY RESEARCH & DEVELOPMENT EXPENDITURE	$
POTENTIAL SHARE OF MARKET - MAXIMUM MARKETING	%
POTENTIAL SHARE OF MARKET - MAXIMUM PRICE	%

OPERATING AND DECISION INFORMATION (for next period)

					DECISIONS LAST PERIOD				
UNIT COST OF PRODUCTION	$ 4.65	$ 4.61	$ 4.57	$ 4.54	$ 4.50	$ 4.49	$ 4.48	$ 4.46	$ 4.45
UNITS OF PRODUCTION	720,000	765,000	810,000	855,000	900,000	918,000	936,000	954,000	972,000
DECISION ALTERNATIVES									
COST OF PRODUCTION	$3,348,000	$3,526,700	$3,701,700	$3,881,700	$4,050,000	$4,121,800	$4,193,300	$4,254,800	$4,325,400
MARKETING		$ 170,000	$ 180,000	$ 190,000	$ 200,000	$ 210,000	$ 220,000	$ 230,000	
RESEARCH & DEVELOPMENT		$ 85,000	$ 90,000	$ 95,000	$ 100,000	$ 105,000	$ 110,000	$ 115,000	
ADDITIONAL PLANT INVESTMENT	$ 0	$ 10,000	$ 20,000	$ 30,000	$ 40,000	$ 50,000	$ 60,000	$ 70,000	$ 80,000
MARKET RESEARCH INFORMATION									
S=COMPETITORS' SHARE OF MARKET M=TOTAL INDUSTRY MARKETING EXPENDITURE R=TOTAL INDUSTRY RES & DEVELOP EXPENDITURES A=POTENTIAL MARKET SHARE-MAX MARKETING P=POTENTIAL MARKET SHARE-MAX PRICE	NONE	$ S 5,000	$ M 10,000 NONE	$ R 10,000 A $ 22,500	$ S&M 15,000 P $ 22,500	$ S&R 15,000 A&P $ 45,000	M&R $ 20,000	S,M&R $ 25,000	
PRICE	$ 4.80	$ 4.85	$ 4.90	$ 4.95	$ 5.00	$ 5.05	$ 5.10	$ 5.15	$ 5.20
PLANT DISPOSAL (in units)				NONE	5,000	10,000			
	1	2	3	4	5	6 COMPANY	7 PERIOD	GAME 8	9
IBM 650 REPORT				TOTAL FUNDS AVAILABLE →	$4,425,000				

Fig. 9. Sample Form Top Management Decision Simulation

and providing satisfactory stocks in their distribution systems.

Results to date seem to indicate that simulation provides a means of more effective training and that it promises to augment and even replace some of the management training methods used in colleges. Therefore, perhaps a brief summary of some of its advantages is of interest.

ADVANTAGES OF TRAINING THROUGH SIMULATION

1. Permits "cause" and "effect" to be felt. The individual can appraise the effect of his actions immediately.
2. Aids in judging what information is really important in making decisions and obtaining management control.
3. Familiarizes the individual with the data needed and available to him in making his decisions, thereby demonstrating economic and management principles in practice.
4. Is a means of providing some familiarization with Electronic Data Processing. This is an extra benefit to many participants who are not already familiar with computers.
5. Decisions must be made from facts available and analyzed immediately. Simulation poses a realistic situation, not an academic one, full of exceptions and sometimes too inconclusive in nature to be satisfying.
6. Because it is more realistic, the students or players get caught up in it and work more intently at the tasks it requires.

The success and utility of a simulation which is aimed at training depends on obtaining "involvement" of the participants, how adequate it represents reality and whether there is a transfer of skill back into the real life situation. At this point in the development of simulation, it is difficult to *prove* scientifically that there is a *real* transfer or that it *is* beneficial to the student.

However, everyone associated with simulation believes that an intelligent individual will not carry away specific acts to perform (unless so directed), but rather will carry away a point of view in tackling problems,

thinking more of the system in which they reside, what courses of action are available, and what facts must be considered. In order to test the nature of what the student retains from his simulation exercise, AMA is having two psychologists build up scales to measure the quality and type of training received.

Thus, simulation training methods also give us the possibility of testing the effect of many training principles, and should prove a most versatile addition to our educational process.

RELATION TO OTHER ANALYTICAL METHODS

This subject is worthy of much discussion beyond the scope of this paper. However, many operations research activities have recognized that there are many classes of problems where the mathematical theory is so difficult to apply that it is much easier to determine probable outcomes in this experimental fashion (4) (21) (24). This is particularly true of many of the problems facing the Industrial Engineer who must deal with partially ordered sets of events. The scheduling problem is a good case in point and we do not have to turn further than our example to illustrate the point.

It becomes exceedingly difficult to evaluate "priority" rules by mathematical means. In the man-machine problem, queueing theory solutions have been worked out for only the "repair in the order of arrival" method of scheduling repair (16). This is about where the theory stops, for as Cobham (7) relates, solutions for multiple repairmen have proved too difficult to obtain. Cobham develops a mathematical solution for the case of one repairman only, certainly not satisfying to the needs of most real problems. As we have seen, simulation can easily explore a number of priority rules and is a versatile tool.

This discussion is not meant to discourage the use of mathematical approaches in this area, but rather to stress the need for additional research. Simulation is proving to be a good running mate for mathematical and economic models and should aid by providing a good operating description of real problems for mathematical researchers. The point here is that one using simulation should not feel inferior in using this less "elegant" approach—it is often more practical.

RELATION TO INSTALLATION THEORY AND THE INDUSTRIAL ENGINEER

The Industrial Engineer must embody within himself something of the mathematician, something of the economist, and something of the psychologist. Chief among his many duties, is the job to criticize, design, and implement, or install new procedures, controls and so forth, that may be suggested as operational changes by results of psychological, economic and engineering research.

In the present world, change in the form of new products and processes is coming at a faster rate than ever before. The life of a new product or process is shorter. All of this adds up to the need for introducing change more efficiently and accurately since the learning time is now a much more significant portion of the product's total life span and cost. While system simulation is no panacea, it offers assistance and is a useful tool in such *installation theory*. As we have seen, it has utility in analyzing complex problems and in training operating management in the system it operates. Companies that clearly recognize that efficiency comes from the real understanding of broad operating objectives on the part of all levels of management involved, will clearly be more flexible and achieve lower cost operations more quickly.

The evidence is clear and encouraging that system simulation is a useful and powerful tool in helping to reduce installation time, in improving the quality of understanding and in searching for system cost reduction opportunities. In this technique would seem to lie the method for Industrial Engineering research into systems design. Simulation projects in many areas of the Industrial Engineer's job will lead to a common language in Industrial Engineering systems and stimulate the growth of supporting mathematical research.

REFERENCES

(1) Alberts, W. E., "Report to the Eighth AIIE National Conference of the System Simulation Symposium," *The Journal of Industrial Engineering*, November-December 1957.

(2) Alberts, W. E., "Systems Simulation," *Proceedings of the Seventh Annual National Conference*, May 17-18, 1956.

(3) Alder, R. B., and Fricker, S. J., "The Flow of Scheduled Air Traffic, parts 1 and 2, Massachusetts Institute of Technology, *Research Laboratory for Electronics Techn. Reports*, May 1951.

(4) Bellman, Richard, Clark, E. E., Malcolm, D. G., Craft, C. J., and Ricciardi, F. M., "On the Construction of a Multi-Stage, Multi-Person Business Game," *Operations Research*, August, 1957.

(5) Boelter, L. M. K., "A Technique of Problem Solution," *Journal of Philosophy*, March 4, 1943.

(6) Bush, G. C., Galliher, H. P., and Morse, P. M., "Attendance and Use of the Science Library at M.I.T.," *American Documentation*, April 1956, p. 87-109.

(7) Cobham, Alan, "Priority Assignment in Waiting Line Problems," *Operations Research*, February, 1954.

(8) De Carlo, Charles R., "Electronic Computers Solving Production-Engineering Problems," *Mechanical Engineering*, May 1956, p. 416-18.

(9) Flood, Merrill M., "New Mathematical Tools for Decision-Making," *Ind. Labs.*, September 1956, p. 50-55.

(10) Goode, H. H., "The Application of a High Speed Computer to the Definition and Solution of the Vehicular Traffic Problem," *Operations Research*, December 1957.

(11) Goode, H. H., "Simulation—Its Place in System Design," *Proc. IRE*, Vol. 39, 1951.

(12) Goode, H. H., Wright, J., and Pollmar, C., "Use of A Digital Computer to Model A Signalized Intersection," Highway Research Board, Washington, D.C., January, 1956.

(13) Hawkins, G. A., and Boelter, L. M. K., "The General Mode of Analysis in Engineering Education," *Journal of Engineering Education*, January 1954.

(14) Jessop, W. Neail, "Monte Carlo Methods and Industrial

Problems," *Applied Statistics*, November 1956, p. 158-65.
(15) Malcolm, D. G., "New Method Pre-Tests Ideas," *Nation's Business*, February 1958.
(16) Malcolm, D. G., "Queueing Theory in Organization Design," *The Journal of Industrial Engineering*, November-December 1955.
(17) Malcolm, D. G., "The New Industrial Engineering," *The Journal of Industrial Engineering*, November-December 1956.
(18) McClelland, W. F., Jarema, D. R., and James, R. M., "Office Automation," *Instruments and Automation*, December 1956.
(19) Norman, R. A., "A Manager Appraises Operations Research," *The Journal of Industrial Engineering*, May-June 1957.
(20) O'Neill, R. R., "Application of Computers to Some Cargo Handling Problems," Logistics Research Project Sponsored by the Office of Navy Research, UCLA, Report 5.
(21) Ricciardi, F. M., Craft, Clifford J., Malcolm, D. G., et al., *Top Management Decision Simulation*, American Management Association, 1957.
(22) Rowe, A. J., and Jackson, J. R., "Research Problems in Production Routing and Scheduling," *The Journal of Industrial Engineering*, May-June, 1956.
(23) Stout, T. M., and Laspe, C. G., "Digital Computers for Process Control," *Ind. Eng. Chem.*, July 1957.
(24) Thomas, Clayton J., and Deemer, Walter L., Jr., "The Role of Operational Gaming in Operations Research," *Operations Research*, February, 1954.
(25) Trautman, D. L., et al., "Analysis and Simulation of Traffic Flow," *University of California, Institute of Transportation and Traffic Engineering Research Report 20, 1954*.
(26) Vaswani, Ram, "Intra-City Trailer Movement," *Operational Research Quarterly*, September 1956, p. 91-96.
(27) "Engineering Research," *Mechanical Engineering*, December 1948.
(28) *Proc. National Simulation Conference*, sponsored by Institute of Radio Engineers, Dallas, January 19-21, 1956.
(29) Project Cyclone Symposium I on Reac. Techniques, Port Washington, N.Y., March 14-16, 1951, SDC, USN.
(30) Project Cyclone Symposium II on Simulation and Computing Techniques, Port Washington, N.Y., April 28-May 2, 1952, SDC and BuAer, USN.
(31) *Report of System Simulation Symposium*, Co-Sponsored by AIIE, ORSA and TIMS, February, 1958, Waverly Press, Edited by D. G. Malcolm.
(32) Symposium on Monte Carlo Methods, March 16-17, 1954, Edited by H. A. Meyer.
(33) Symposium III on Simulation and Computing Techniques, Port Washington, N.Y., October 12-14, 1953, BuAer and NADC, USN.

Operator Performance Studies: I—One-Plane Motion Learning[1]

by **GERALD NADLER**

Professor and Head, Department of Industrial Engineering, Washington University

and **JAY GOLDMAN**

Assistant Professor, Department of Industrial Engineering, Washington University

INDUSTRIAL ENGINEERING is an expanding field. This is true for both the number of areas included, and for the depth to which the present areas are being explored and utilized. The expansion is greater in the latter, in terms of accuracy, thoroughness and precision of the techniques needed for finding the answers in the present areas. For example, inventory control, scheduling, plant layout, production planning, and plant location have usually been considered areas in Industrial Engineering. But these areas are the ones now being attacked with new and better techniques. Although many of the new techniques can be used for other fields, like sales, development, market research, etc., these areas are not really being added to Industrial Engineering; they are merely recognizing the need for better techniques, many of which were developed in and are sponsored by the Industrial Engineering field. Incidentally, many of the other areas of Industrial Engineering, like work simplification, work measurement, incentives, and materials handling are likewise being subjected to new approaches to effect new results.

One important aspect of the new techniques is the ability to tie together the individual variables affecting a problem. To make the new techniques useful, data from other techniques, and assumptions from the practitioners, are needed. If the original data are not accurate, or are founded on improper bases, the techniques do not represent a practical advance or an over-all theory.

No technique or concept is usually stronger, more valid or useful than the weakest component in that technique. So as research into new and necessary techniques for over-all concepts proceeds, it must be accompanied by more and expanded research into techniques providing some of the fundamental data.

WORK MEASUREMENT

Probably the most widely known and used basic technique in Industrial Engineering is work measurement. Its time results are essential for most other techniques in

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Industrial Engineering. Because of this it should be one of the most accurate tools. Yet it is not. The problems are well known: What is a motion? What is a correct motion pattern for a methods description for a job? How can differences between operators on the same job be detected? What is skill? How is it possible to know when proper training has been achieved? How is operator performance measured? What is the effect of difficulty on the pace or performance of an operator? What is fatigue? Most of these problems affect one other problem: How do we rate, or measure, operator performance? This is one of the most controversial steps in work measurement.

Attacking these problems in work measurement seems difficult, except that every problem mentioned is in some way related to the actual performance or motions of an operator. If every motion could be measured in every detail, then a start toward answering most of the problems could be made by investigating the motion components for relationships among themselves and with external criteria. Such a measurement is now available in the form of UNOPAR (3) (8).

LEARNING

Most definitions of time study and/or of rating mention learning in one way or another. This appears as a statement or problem more often than any other factor. Schutt says, "Standard time . . . required by an operator who possesses normal skill and normal training . . ." (10). Lowry, Maynard, and Stegemerten say, "Skill may be defined as proficiency at following a given method" (4). The word proficiency implies the learning or training concept. Barnes says, "The result of time study is the time in minutes that a person suited to the job and trained in the specified method will need to perform the job . . ." (1). Segur says, "Within practical limits the times required of all expert workers to perform true fundamental motions are constant" (11). Expert includes a learning function. Mundel says a standard time is defined with the stipulation that it be performed "by a worker possessing a specified amount of skill on the job and specified aptitude for the job" (5). Then skill is defined as "the ability to do a job in the proper manner; the ability to repeat a definite muscular pattern." Nadler says a standard time is defined with the following restriction in establishing the time: "When worked on by an operator with the necessary skill and given sufficient training to perform the operation properly, . . ." (6, p. 304).

In addition, learning is important to many activities in other areas of Industrial Engineering and in other fields of endeavor. Training concepts, selection of personnel, design of equipment, fatigue, psychology, physiology, job evaluation, merit rating etc., are areas interested in or dependent on learning.

Yet what is learning? To date, learning research used over-all criteria such as learning curves, in investigating this problem. Learning curves help in establishing over-all definitions, and in some aspects of basic understanding, but they are by no means sufficient. Similarly other techniques have not been able to probe into the depths of the learning process. For example, research at Washington University has shown that the times for all therbligs do not decrease in the same proportion as training (or learning) increases (7) (9). Apparently, it is even essential to make learning studies of individual motions within the over-all operation. This should provide needed insight into the learning process.[2]

PURPOSE OF THE EXPERIMENT

Learning is a complicated factor being affected by many variables. In spite of the many parameters, like mental skill, visual acuity, and mechanical dexterity, it seems appropriate to investigate only the *effects* of these and many factors on the performance of a task. In this case, learning is the process of repeating a task over and over to meet the objective established for the task (quality) at a rate of performance considered satisfactory (quantity). To simplify the concept, the rate of performance is established as "as many cycles per time unit as possible within the ability of the individual and the incentive circumstances." The effects of the individual performance are reflected in the motions performed by the individual (8).

The objective of this experiment was to determine the effects of learning on the operator performance of a simple motion.

EXPERIMENTAL MOTION

The nature of this experiment is relatively exploratory. Learning was defined in a simple manner. Likewise, it was essential to have a motion which was extremely simple.

In previous experimentation, a simple motion has usually been one between two points performed in three dimensions. However, it appeared essential in this experiment to start with even a simpler motion. This would provide the greatest control of the activity. This control was necessary for experimentation into the basic learning process, and because of the newness of the type of data obtainable from the UNOPAR. Also the amount of data is absolutely tremendous. This meant it was essential to know exactly what the motion was so that proper interpretations could be made from the UNOPAR data. If a three dimensional motion had been used, there would be no way of having a base reference about the exact path of the motion to compare with the UNOPAR records.

[2] In addition to (7) and (9), there have been many other experiments which tend to show the same effect. Many of these have been performed by K. U. Smith at the University of Wisconsin, and others have been performed in various places like Cornell University, University of Iowa, and by private concerns.

To go even further, it was decided that the motion would involve that of a speaker in a frame. Therefore, the experiment consisted of a simple, one plane motion in which the subject learned to apply a specific force at both ends of the motion.

APPARATUS

The various pieces of equipment utilized in this experiment were as follows:

1. Experimental test motion table. The experimental table (Figure 1) is the base for a small frame which moves on roller bearings over covered steel rods from one end of the table to the other. This assured only one plane motions by the subject. The force which the subject learned to apply at each end of the motion was provided by the force levers which can be seen at the front and back of the table projecting through the table top. Forces were maintained on these levers through springs which can be seen suspended between the linkage below the table and a fixed bar. It was possible to exert up to ten pounds of force on either bar by pushing the lever to the maximum displacement position. Connected to each force lever below the table were three electronic control devices. These are shown in the wiring along the lower horizontal support. These controls operated: (a) a buzzer system which indicated that the force being applied was within the tolerance limit (the amount of tolerance was a variable established by the experiment), (b) the circuity to enable an actual plot of the force on the force channels of the oscillographic recorder, and (c) a cycle counter (which was energized by the displacement of the force lever away from its rest position). This table was rigidly bolted to the floor so that all motions are restricted to the movements of the frame on the steel rods.

2. The UNOPAR. The velocity of the hand-speaker-frame was measured continuously against time by the UNOPAR. the UNOPAR speaker can be seen rigidly attached to the frame in Figure 1, and moves with the frame and the body member pushing the frame. The motions recorded by the UNOPAR are those of the speaker, which for this case was assumed to be virtually the same as the motions performed by the body member (hand). (Because the hand actually twists somewhat on the freely pivoting handle as it moves the rack over the steel rods, this assumption is not necessarily correct. However, it has no bearing on the results of the experiment, since the results are concerned with the learning process as exhibited by single vector of the hand motion; this was the most important component of the hand's activity in this experiment. Later experiments will have the speaker attached to the body member using the same test set-up, to measure the work of the body member itself.)

The measurements plotted against time taken *continuously* during the experiment performance were as follows: (a) velocity, (b) force imparted at the front of the motion, (c) force imparted at the back of the motion, and (d) number of cycles completed. Mathematical treatment of the velocity versus time data would provide acceleration, deceleration, position and displacement information continuously.

3. Cycle timing control. The control of the work-rest periods was affected by the use of the light box shown at the left of Figure 1. The electronic control for the light box is shown on the floor behind the experimental test apparatus in Figure 1. This device is an electronic timer having variable timing limits and a recycling feature. This enables the experiment to be established with the work-rest relationship set for any given combination of time periods and once set, will recycle at the settings. The upper light was the rest light, and the lower light was the work light.

4. The UNOPAR tape analyzer (Figure 3). This was a simple device to enable analysts to obtain information from the oscillographic recorder tape. Measurements made on the tape here were the forces, velocity, time, acceleration, deceleration, and various combinations of these measurements, as described later.

FIG. 1. Experimental Test Motion Table

PROCEDURE

The amount of force at the force levers was selected as 3 lbs., and the tolerance amount was plus or minus ¼ lb. in one experiment (subject JB) and plus or minus ⅛ lb. in the other (subject BK). The distance between points of application of force was 19 inches. A warning buzzer was sounded when the subject applied the minimum acceptable force and continued to be sounded until the subject had applied the maximum tolerable force. This warning was initiated automatically at both ends of the motion.

Subjects were informed that they were to perform this operation as fast as possible and yet maintain the necessary accuracy. Throughout the experimental runs they were constantly reminded of the criteria of accuracy and speed. The experimental runs consisted of work periods of 30 seconds each followed by rest periods of 10 seconds. These runs were automatically controlled by the light timing device which flashed the working (green) light and rest (red) light.

The entire project and its over-all objectives were explained to each subject. The operation of the experimental apparatus and the measuring devices were demonstrated to the subject. The subject was then told the exact position to assume in the performance of the task and placed in this orientation. The subject was to stand so that the handle of the experimental apparatus was grasped with the forearm of the subject perpendicular to the body at the middle of the 19 inch travel motion. The subject was allowed to try the task *once* to observe the action of the control buzzer device, which indicated that the correct pressure had been applied.

The subject then grasped the handle and when the work (green) light was flashed, he began the experiment

by pushing the rack toward the forward force lever and applying the force there. Then he moved the rack backward and applied the force there. This motion was continued until the rest light was flashed. Then the work-run periods started again when the work light flashed again.

Three subjects were used in this experiment. Originally, more subjects had been contemplated to obtain usual group analysis data. The first subject performed for five 30 second test periods. From this extremely short test, it became apparent that the data handling problem would be overwhelming. So much information is obtained from one simple motion through the UNOPAR records that the contemplated data handling system (mainly manual) would not allow any where near the proper type of evaluation of the data available from a normal experiment.

Therefore, it was decided in this preliminary experiment to run only two more subjects for more prolonged test runs, because much information could be gathered even from individual subject UNOPAR tape records. In addition, this information would be valuable in es tablishing the next stage of the experiment.

All the information used in the analysis of the results were obtained by reading the information from tape records. This was a tedious and lengthy job. The type of data collected is summarized in the next section. The correlation coefficients were determined by using a 650 digital computer.

RESULTS

All the direct results were obtained in the form of tape recordings from the oscillographic recorder. Figure 2 shows the information obtained from one complete 30 second work-run period of one subject. Each of the lengthy tests were analyzed, and the data summarized in the form shown in Table 1 (Sample). It should be observed that for each 30 second work-run period only one set of values for acceleration, and velocity and deceleration was obtained. The cycle which was analyzed was selected at random from among those good attempts or cycles charted at the maximum tape speed of 125 mm per second. This does not include all the information concerning each run, but the extraordinary amount of information available would have required a prohibitive amount of time for the manual analysis procedure. In addition, it was also decided for the same data handling reasons not to integrate and differentiate the velocity curves to obtain the position-displacement and acceleration-deceleration curves. Therefore the values of peak acceleration and peak deceleration were estimated from the maximum slopes of the velocity curves. All these compromises in reduction and accuracy of some data were dictated because of the vast amount of information available.

Some of the information included in the analysis is a continuous reading of values from the velocity curve, the actual acceleration-deceleration curves, the actual position-displacement curves, readings from each of these other two curves in a continuous manner, calculations to compare shape and size of curves at various stages of the learning process, inaccuracies of visual readings of peak acceleration, and so forth. This information and the calculations as a result of the availability of this information should become available for analysis of forthcoming experiments when electronic data processing plans are completed.

Even so, much extremely valuable information has been forthcoming, which portends much for the future when all the data will be susceptible to analysis.

The list of basic and calculated data follows (the data are listed with the code numbers used for the analysis through the Digital Computer):

01	Run Number	Run = 30 second test
02	Cycles/run	Cycle = one motion forward + one motion backward
03	Forward force	(Number of good attempts for forward motion per run)
04	Backward force	(Same for backward motion)
05	Peak velocity for forward	
06	Peak velocity for backward	
08	Total forward motion time	
09	Total backward motion time	
11	Time spent in acceleration forward	
12	Time spent in deceleration forward	
13	Time spent in acceleration backward	
14	Time spent in deceleration backward	
15	Peak acceleration forward	

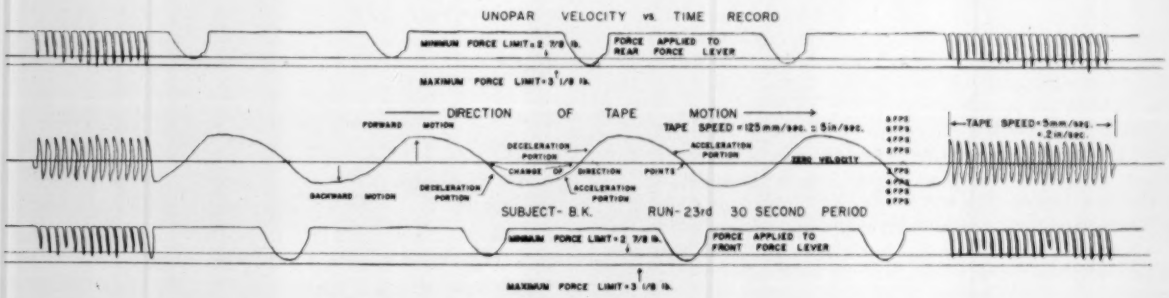
UNOPAR VELOCITY vs. TIME RECORD
FORCE APPLIED TO REAR FORCE LEVER
DIRECTION OF TAPE MOTION
TAPE SPEED = 125 mm/sec. ± 5in/sec.
TAPE SPEED = 5mm/sec. ± .2in/sec.
FORWARD MOTION
BACKWARD MOTION
DECELERATION PORTION
ACCELERATION PORTION
CHANGE OF DIRECTION POINTS
ZERO VELOCITY
SUBJECT- B.K. RUN- 23rd 30 SECOND PERIOD
FORCE APPLIED TO FRONT FORCE LEVER

FIG. 2. Tape Record—30 Second Run Period

TABLE 1

Summary of Data Collected from Subject J.B. (sample)

Run	Cycles Run	Cycle	Dir.	Force In	Duration Distance	Peak Vel.	Acceleration Distance	Deceleration Distance	Maximum Acc.	Slope Dec.
1	34	16	F	32	62.0	4.52	37.0	25.0	26.9	36.8
			B	0	60.0	5.24	29.7	30.3	32.6	37.3
2*	8	39	F	—	33.5	6.80	19.6	13.9	52.5	63.1
			B	—	33.3	7.96	19.0	14.3	56.0	64.0
3*	44	77	F	35	32.8	6.2	18.9	13.9	26.0	32.2
			B	15	33.0	8.3	21.3	11.7	28.0	41.9
4*	26	99	F	24	41.9	8.1	24.2	17.7	29.5	30.2
			B	1	31.7	7.2	21.0	10.7	28.5	45.6
5	54	161	F	41	37.2	7.0	22.0	15.2	50.0	61.4
			B	7	33.0	8.2	19.8	13.2	54.0	66.5
6	36	199	F	24	38.6	6.84	23.2	15.4	53.0	59.0
			B	8	32.5	7.76	23.4	9.1	50.5	71.5
7	40	237	F	34	36.1	6.92	21.8	14.3	54.9	57.5
			B	2	30.7	7.96	20.9	9.8	53.3	71.4
8	28	251	F	22	36.8	6.80	22.9	13.9	56.2	60.6
			B	12	34.6	7.12	21.4	13.2	50.1	66.7
9	53	308	F	49	37.8	7.24	22.6	15.2	50.4	60.3
			B	27	32.5	7.60	22.1	10.4	49.6	69.5
10	57	361	F	46	34.3	6.96	21.5	12.8	63.0	63.2
			B	27	32.6	7.64	20.7	11.9	54.5	66.9
11	54	410	F	48	35.7	6.36	22.2	13.5	51.6	65.0
			B	13	35.9	7.92	23.7	12.2	51.5	66.8
12	53	469	F	47	40.9	6.92	24.8	16.1	54.5	56.0
			B	6	37.9	6.16	23.3	14.6	43.4	64.1
13	49	525	F	45	40.0	7.56	24.8	15.2	54.3	56.6
			B	0	34.0	7.32	22.1	11.9	49.7	68.7
14	53	584	F	45	38.2	6.80	24.6	13.6	50.0	67.2
			B	6	33.5	7.28	22.8	10.7	52.9	70.6
15	53	635	F	46	40.0	6.40	27.4	12.6	46.5	63.0
			B	20	34.5	6.64	21.9	12.6	50.7	67.7
16	52	673	F	43	40.0	6.36	24.9	15.1	48.6	56.9
			B	39	32.9	6.88	22.6	10.3	51.6	72.0
17	52	732	F	50	36.8	5.96	22.8	14.0	53.3	63.0
			B	43	32.0	6.84	20.1	11.9	54.5	68.0
18†	—	—	—	—	—	—	—	—	—	—

* Data for these runs were not used in the correlation because of: scale changes, incomplete run, change of speed, of recording device, etc.

† These runs were not monitored.

16 Peak deceleration forward
17 Peak acceleration backward
18 Peak deceleration backward
19 Percent of time spent in acceleration in forward motion
20 Percent of time spent in deceleration in forward motion
21 Percent of time spent in acceleration in backward motion
22 Percent of time spent in deceleration in backward motion
23 Acceleration time/deceleration time for forward
24 Acceleration time/deceleration time for backward
25 All times in acceleration (f + b)
26 All times in deceleration (f + b)
27 All peak accelerations (f + b)
28 All peak decelerations (f + b)
29 All percent acceleration times (f + b)
30 All percent deceleration times (f + b)

The criteria measurements for most analyses were Run Number 01, Cycles per run 02, Total forward time 08 and Total backward time 09. Good attempts (meeting the force requirements at the end of a motion) 03 and 04 were determined for each run period. This information was not considered too useful since the measuring components developed trouble which led to errors in recording. An obvious criterion, total good attempts per run divided by total attempts per run, was not used because of these errors. However some graphical analyses were made using this information but these were not too significant. The 01 (run no.) figures are meaningless, but all data as obtained from the computer are presented.

ANALYSIS OF THE RESULTS

Basically, the data were analyzed in respect to the following outline.

1. Individual analysis
   (a) Qualitative
   (b) Graphical
   (c) Quantitative
2. Group analysis
   Significance of difference tests (this was the only group test applied for this experiment because there were only two subjects from whom sufficient data were collected. When the usual number of subjects are used, it will be possible to use other group analysis techniques).

1. INDIVIDUAL ANALYSIS

(a) Qualitative analysis. Since this type of analysis depends strictly on the observation of the curves itself, the conclusions drawn from such observation are listed under the conclusion of this paper.

(b) Graphical analysis. Many types of graphs are possible with the data collected. Many of these graphs are overlapping with some of the correlations discussed under the quantitative analyses. Only those graphs of

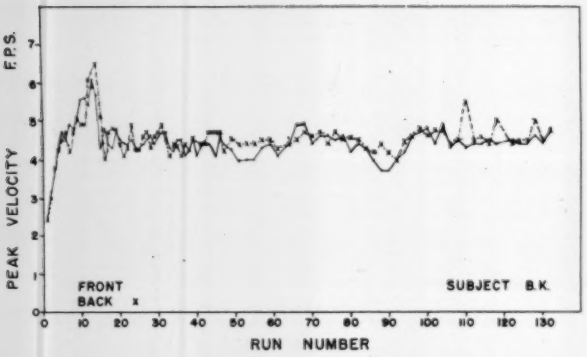

Fig. 3. Peak Velocity vs Run Number for B.K.

most importance and significance are shown.

From the data available, the following graphs were constructed: good attempts forward versus good attempts backward, peak deceleration versus time, good attempts back versus run number, good attempts forward versus run number, deceleration time versus total time, acceleration time versus total time, peak velocity versus run number, percent deceleration time versus run number, ratio of acceleration time to deceleration time versus run number, percent acceleration time versus run number, peak velocity versus total time, peak acceleration versus run number, and peak deceleration versus run number.

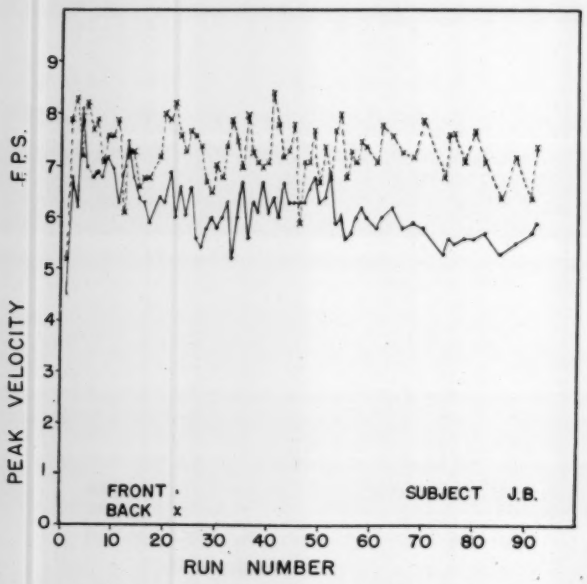

Fig. 4. Peak Velocity vs Run Number for J.B.

Some of the more interesting graphs are shown in the following figures. Figure 3 shows peak velocity plotted versus run number for subject BK, and Figure 4 shows the same graph for subject JB. These curves show the slight downward trend after the peak velocity had reached its maximum value. Subject BK shows a more pronounced learning maximum and drop. Also, the front motion peak velocity decreases at a more rapid rate than does the back peak velocity. The forward motion is that of the arm moving toward the left-hand side of the body (the front of the body is parallel to the vertical plane which contains the one plane motion). This motion is usually considered as the one capable of imparting the greatest force and/or velocity.

Figure 5 shows the peak acceleration plotted versus the run number for subject BK, and Figure 6 shows the same graph for subject JB. These graphs tend to show the usual learning curve effect. There is virtually no change after the first five runs. In a sense, learning has been accomplished for this task at an early point. In some ways, such a task could be used for selecting persons once criteria were established on the proper number

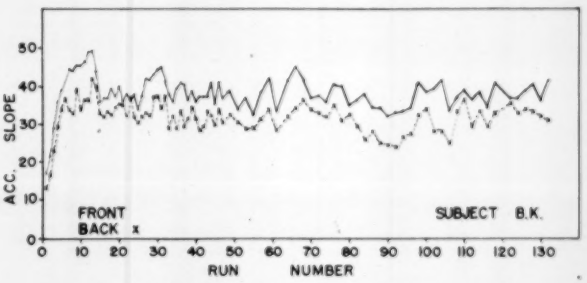

Fig. 5. Acceleration Slope vs Run Number for B.K.

of runs to be used. Another interesting facet concerns the very noticeable downward trend of Figure 5. Also, there seems to be a cyclic behavior attached to the acceleration as the run number increases. This might indicate the presence of a cyclic phenomena in the performance pattern of the individual.

Figure 7 shows the good attempts backward plotted versus the run number for subject BK. It has been noted that the recording apparatus for the force applied

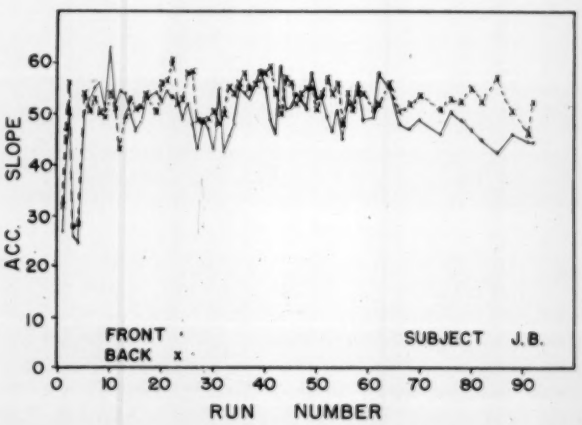

Fig. 6. Acceleration Slope vs Run Number for J.B.

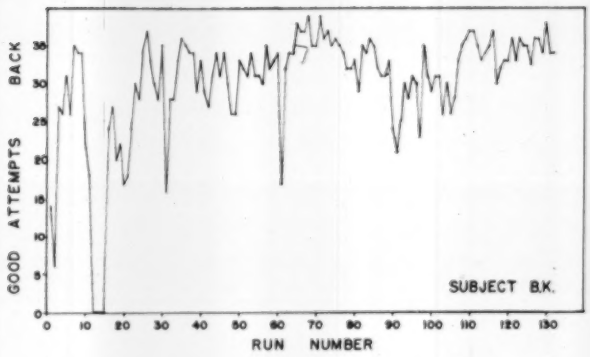

FIG. 7. Good Attempts Back vs Run Number for BK

was not working properly, therefore errors exist in determining the good attempts. However, the mechanism was working for this test for BK. In Figure 7 the cyclic characteristic is again apparent.

The learning curves from this experiment are more unusual than curves ordinarily obtained. The experiments, and therefore the curves, continued on far beyond the attainment of the peak or "plateau" value. There is little reference in the psychological literature to the learning curve beyond plateau attainment. "Most actual curves are cut short at both ends since we neither start from absolute zero of practice nor do we carry the subject to his absolute ability" (12). Consultation with a psychologist developed the point that there is no adequate explanation for such cycles as yet, although there is some discussion among psychologists that such cycles are present in moods and even smaller portions to work. Such cyclic behavior in learning curves would be in opposition to the usual concept of random fluctuations around the fitted curve. In future experimentation of the type reported here, the testing will continue for much longer periods of time to check the cyclic behavior. In addition the task will be made more difficult to help make longer the period of time needed to reach the plateau.

(c) Quantitative analysis. Pearsonian correlation coefficients were found for each pair of values given above. These are summarized in the correlation matrices shown in Table 3.

Since it was easier for the Computer to do the entire multiple correlation matrix analysis, correlation among all the variables were obtained. As can be expected, most of the correlation values could be expected and were generally meaningless. Some of these other correlations might eventually develop some interesting results. Part I and Part II were established because the number of pairs being correlated were different in the two parts.

In discussing the significant correlation coefficients, two factors should be noted:

1. The discussion will be related to the four criteria, time forward, time back, cycles per run, and run number. Other correlation coefficients, although presented in the matrix, were not necessarily significant, or their high significance had no real meaning.

2. Significance for these cases was calculated by means of the standard error of the correlation coefficients. From the calculations, a standard error of .05 or less was obtained for correlation coefficients of .77 or more. A standard error of .10 was found to apply to values of around .50. Therefore anything above .77 was considered significant, and anything below .50 was not considered significant. Between the two values at .50 and .77, the correlation coefficients were considered possibly significant.

There was nothing of significance in the correlations with run number 01. Peak velocity back 06 had the highest value at .51 (subject BK), and backward force 04 at .52 for subject JB.

In relation to cycles per run 02 several interesting correlations were noted. For subject BK, there is a high positive correlation between cycles per run and all peak acceleration and deceleration values 15, 16, 17, 18. There was no significant correlation with any of the percent times for acceleration and deceleration 19, 20, 21, 22. In effect, this means there is a relatively constant percent acceleration and percent deceleration time in a motion. There is a somewhat negative correlation with time spent in acceleration and deceleration 11, 12, 13, 14. (As cycles per run increase, time spent in acceleration and deceleration should decrease.) There was a high significant negative correlation with total time 08 and 09. For subject JB there was really no significant correlation at all, even though subject BK had the three interesting highly correlated activities. The nonsignifi-

TABLE 2

Average and Standard Deviation for the Values of each item measured for each Subject

Item Measured	SUBJECT B.K. Average	SUBJECT B.K. Standard Deviation	SUBJECT J.B. Average	SUBJECT J.B. Standard Deviation
01	44.50	25.40	34.50	19.62
02	4.47	0.47	52.01	6.29
03	4.55	0.50	44.87	8.22
04	37.34	3.64	35.74	13.74
05	24.65	8.48	6.21	0.53
06	29.02	8.37	7.31	0.55
08	51.08	6.01	37.81	3.63
09	52.37	5.37	34.17	3.72
11	30.18	4.60	23.88	2.31
12	20.91	2.68	13.94	1.91
13	32.59	4.12	21.11	1.93
14	19.78	1.95	13.06	2.53
15	38.24	4.76	50.53	5.28
16	43.00	4.94	64.49	4.99
17	31.81	4.40	52.89	4.07
18	42.91	5.45	66.93	4.61
19	58.95	3.98	63.16	2.87
20	40.99	4.07	36.84	2.87
21	62.08	2.52	61.90	3.77
22	37.93	2.51	38.10	3.77
23	1.46	0.25	1.73	0.24
24	1.65	0.17	1.65	0.27
07	4.51	0.48	6.71	0.93
25	31.39	4.53	22.49	2.54
26	20.35	2.41	13.50	2.28
27	35.03	5.60	51.71	4.86
28	42.96	5.20	65.71	4.96
29	60.52	3.68	62.53	3.41
30	39.49	3.67	37.47	3.41

TABLE 3
Correlation Matrix

SUBJECT BK

	01	02	03	04	05	06	07	08	09	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
01	1.00																												
02	−.10	1.00																											
03	.07	.76	1.00																										
04	.01	.52	.42	1.00																									
05	−.19	.09	.10	.31	1.00																								
06	.51	−.20	−.27	.18	.10	1.00																							
07							1.00																						
08	−.20	−.76	−.73	−.54	−.20	−.20		1.00																					
09	−.28	−.77	−.72	−.50	−.24	−.21		.94	1.00																				
11	−.11	−.68	−.61	−.57	−.26	−.20		.91	.81	1.00																			
12	−.25	−.52	−.59	−.22	.01	−.12		.69	.71	.31	1.00																		
13	−.25	−.72	−.69	−.56	−.25	−.23		.91	.95	.79	.69	1.00																	
14	−.23	−.60	−.53	−.19	−.12	−.09		.67	.75	.58	.50	.51	1.00																
15	−.07	.85	.74	.52	.14	−.05		−.81	−.80	−.75	−.54	−.73	−.65	1.00															
16	.11	.77	.75	.43	.19	.07		−.91	−.90	−.76	−.74	−.86	−.66	.83	1.00														
17	−.10	.77	.75	.49	.34	−.06		−.82	−.83	−.71	−.61	−.82	−.56	.81	.84	1.00													
18	.19	.78	.85	.47	.21	−.02		−.81	−.87	−.69	−.65	−.78	−.76	.82	.84	.79	1.00												
19	.10	−.20	−.08	−.31	−.23	−.07		.25	.15	.63	−.53	.14	.13	−.24	−.08	−.15	−.10	1.00											
20	−.09	.21	.08	.30	.23	.06		−.25	−.15	−.63	.52	−.14	−.13	.24	.07	.15	.10	−.99	1.00										
21	−.04	−.20	−.23	−.35	−.17	−.14		.30	.28	.25	.24	.56	−.41	−.16	−.27	−.37	−.10	.01	−.01	1.00									
22	.05	.20	.23	.36	.18	.14		−.30	−.28	−.25	−.25	−.56	.41	.16	.28	.36	.10	−.01	.01	−.99	1.00								
23	.11	−.22	−.10	−.32	−.29	−.07		.26	.17	.63	−.51	.15	.14	−.26	−.11	−.18	−.12	.97	−.96	.02	−.01	1.00							
24	−.01	−.14	−.16	−.31	−.18	−.14		.19	.18	.15	.17	.46	−.48	−.09	−.18	−.31	−.02	−.01	.01	.97	−.97	−.00	1.00						
25							−.64																	1.00					
26							−.52																	.30	1.00				
27							.60																	−.77	−.30	1.00			
28							.81																	−.74	−.71	.67	1.00		
29							−.15																	.63	−.53	−.45	−.08	1.00	
30							.15																	−.64	.53	.45	.08	−1.00	1.00

SUBJECT JB

	01	02	03	04	05	06	07	08	09	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
01	1.00																												
02	.20	1.00																											
03	.30	.65	1.00																										
04	.52	.54	.45	1.00																									
05	−.44	.17	−.08	−.39	1.00																								
06	−.04	.27	.14	.14	.21	1.00																							
07							1.00																						
08	.02	−.46	−.17	−.33	−.42	−.69		1.00																					
09	−.08	−.46	−.11	−.28	−.54	−.49		.82	1.00																				
11	.14	−.30	−.08	−.18	−.43	−.60		.89	.69	1.00																			
12	−.13	−.51	−.24	−.41	−.28	−.58		.83	.72	.47	1.00																		
13	−.27	−.44	−.02	−.33	−.32	−.38		.61	.78	.47	.58	1.00																	
14	.09	−.34	−.15	−.17	−.56	−.44		.74	.88	.65	.61	.38	1.00																
15	−.15	.30	.07	.04	.63	.35		−.69	−.66	−.64	−.54	−.50	−.60	1.00															
16	.30	.57	.26	.51	.19	.52		−.82	−.68	−.64	−.77	−.66	−.50	.46	1.00														
17	.19	.48	.19	.40	.27	.65		−.80	−.75	−.62	−.77	−.71	−.56	.47	.78	1.00													
18	−.06	.42	.11	.21	.55	.51		−.79	−.87	−.68	−.68	−.46	−.93	.62	.61	.67	1.00												
19	.22	.32	.20	.29	−.47	.14		−.15	−.17	.33	−.67	−.22	−.88	.56	.29	.31	−.15	1.00											
20	−.22	−.32	−.20	−.29	.47	−.14		.15	.17	−.33	.67	.22	.88	−.56	−.29	−.31	.15	−1.00	1.00										
21	−.31	−.03	.11	−.09	.38	.16		−.30	−.38	−.31	−.18	.28	−.77	.27	.01	.06	−.63	.08	−.08	1.00									
22	.31	−.03	−.11	.09	−.38	−.16		.30	.38	.31	.18	−.28	.77	−.27	−.01	−.06	.63	−.08	.08	−1.00	1.00								
23	.22	.28	.14	.27	−.07	.14		−.13	−.16	.34	−.66	−.23	−.06	.04	.27	.30	.13	.98	−.98	−.11	.12	1.00							
24	−.38	−.03	.05	−.16	.38	.16		−.22	−.30	−.25	−.12	.35	−.70	.23	−.06	.02	.58	−.10	.10	.98	−.98	−.13	1.00						
25							−.49																	1.00					
26							−.31																	.44	1.00				
27							.51																	−.67	−.55	1.00			
28							.35																	−.59	−.85	.57	1.00		
29							−.06																	.34	−.67	.01	.40	1.00	
30							.06																	−.34	.67	−.01	−.04	−1.00	1.00

cant correlations for JB also applied to the percent of acceleration and deceleration.

In relation to total times 08 and 09, there was a high degree of correlation between the two themselves. For BK, both time values were highly correlated with the times in acceleration 11 and 13 but not so highly related with time in deceleration 12 and 14. This might be expected, but it appears here that acceleration is more dominant in determining total times. For subject BK, both values were highly negatively correlated with peak acceleration and deceleration values 15, 16, 17, 18 with the peak deceleration values slightly higher. In the same manner as with cycles per run, neither time values were highly correlated with percent acceleration and deceleration values. There was likewise no correlation with peak velocity. For subject JB, the same relative relationships were found for the total times in relation to themselves. There were significant values in relation to peak acceleration and deceleration but there was not the degree of dominance of one over another. For the other factors, subject JB had the same type relationships, except some of the correlations were not quite as high. Subject JB did have a negative .69 correlation of peak *velocity backward* with *forward* time. The conclusions take note of this relationship.

In general, both subjects showed the following results, but subject JB did not have as significant values as BK. Time spent in acceleration backward is correlated with peak deceleration forward. Peak deceleration forward is correlated with peak acceleration backward. Likewise peak acceleration forward is correlated with peak deceleration backward. These results indicate there is some relationship among motions. For all practical purposes, the percent of time in acceleration and deceleration are not related to other factors.

In reviewing the second part correlations, subject BK had somewhat significant values relating peak velocity with other factors like time in acceleration, time in deceleration, peak acceleration slopes, and peak deceleration. These are somewhat to be expected because of the decreased time a higher peak velocity should develop. Of probably greater significance is the relationship between peak deceleration and time in acceleration. This shows the somewhat dependent nature of motions. Other values of significance were those which could be expected. For subject JB these results were not the same. As a matter of fact, there are no significant coefficients worthy of discussion.

Non-linear correlation coefficients were not used because linear correlations provided satisfactory approximations in view of the accuracy of the data, and insufficient evidence that any data were really non-linear. Such analyses will be used in future work, especially on borderline linear correlation cases (non-linear correlation values will be essentially higher than linear correlation values).

2. GROUP ANALYSIS

The significance of difference tests could be made for two general classes of information.

(A) For means of various measurements. These tests would not be useful because it is already general knowledge that significant differences from person to person should be expected. Since there is no effective way of separating the operator effects from other variables (as in analysis of variance), no significance of difference tests were calculated for the raw data itself.

(B) For the correlation coefficients. In general, the significance of difference tests for correlation coefficients were used only where it appeared necessary to draw proper conclusions. For example, cycles per run 02 were highly correlated with peak acceleration and deceleration values 15, 16, 17, and 18 for subject BK, but these values were not particularly related for subject JB. By using the critical ratio approach for testing difference significance, there was a certainty beyond reasonable doubt that there was a significant difference in most of these correlation coefficients. This affects the strength of any conclusion which might come from subject BK's data. The correlations between cycles per run 02 and time in acceleration and deceleration were likewise different for the two subjects. There was only a fairly certain significant difference (a critical ratio of 2 to 3) for three of the four values in this series. This same result was obtained from the correlation concerning total time.

In relation to the total time correlations 08 and 09, it was pointed out that subject BK had high correlation with peak acceleration and deceleration 15, 16, 17, 18, but that subject JB's correlations were not as high. There was only one out of eight critical ratios which was high enough to conclude there was a fair degree of certainty that a significant difference was present. Subject JB showed a significant correlation of time with peak velocity, and this was significantly different from correlation for BK.

For some of the other correlations, for example, between 13 and 16, and between 15 and 18, there was a significant difference. This substantiates the previous comments indicating that subject JB did not have correlations as high as subject BK.

CONCLUSIONS

The conclusions from this experiment are somewhat limited because of experimental difficulties and the difficulties of handling the data. This is apparent from the way the analyses were made. In particular, the sections entitled Qualitative Results and Qualitative Conclusions, indicate the nature of these remarks.

As in all research, these limitations in many cases point the way toward more experimentation and future research projects. With this in mind, the conclusions will be presented in two sections. One will concern those made from a qualitative analysis, and the other will concern those made from the quantitative and graphical analyses.

QUALITATIVE CONCLUSIONS

1. *Absence of change-in-direction delay.* As noted on the UNOPAR tape (Figure 2) the velocity plot moves directly

through zero (across the center line of the velocity curve) with no pause or hesitation due to the change in direction. This finding agrees in many respects with simple harmonic theory. Classical motion and time study concepts indicate that delay time should be expected with a change in direction.

2. *Acceleration is much slower in almost every case than deceleration.* (This conclusion is limited to the experimental motion of this test; other motions may provide a different pattern.) The peak acceleration in almost every cycle is much less than the peak deceleration. This is a reversal of the hypothesis that most engineers accept; that a person tends to accelerate more quickly and then drift or decelerate more slowly back to zero velocity when he attempts to stop for the purpose of (like this experiment) overcoming a force at the end of the motion.

3. *There is a very rapid deceleration near the point of initial contact with the force lever.* In every case there is a very rapid deceleration indicated by the steeply-sloped, small deceleration portion of the velocity curve (slight bump on the back side of the curve). This indicates there is a considerable change in velocity slightly after the point of initial contact with the force lever. The velocity of the subject's hand was decreased because the force he was trying to overcome increased, or he recognized that he now had to start greater control of his motion. Another point of significance here is the sensitivity of the measuring device UNOPAR.

4. *Effects of learning.* There is some indication that the curve shape and appearance change with increased learning. When better quantitative analysis techniques are available this should be a highly significant value of UNOPAR measurement. At the beginning of the operation, the velocity curves have a somewhat flat-topped appearance with a non-symmetrical distribution about the peak velocity point as axis. However, as the number of cycles increase, the velocity curves become more sinusoidal in shape, but still non-symmetrical. There is not the flat-topped appearance, and there is an indication that the curves tend to become more symmetrical. The patterns themselves become much more smooth and rounded in their formulation, and this could be an indication of learning.

5. *No observable constant velocity.* Contrary to classical belief (2) that motions are comprised of a certain period of acceleration (40% of the time) a period of constant velocity (20% of the time) and a period of deceleration (40% of the time) the velocity plot indicates there is no such thing as a period of constant velocity. There is simply a period of increasing acceleration to a peak velocity point and then a period of decreasing deceleration back to the zero or change of direction point. This has important connotations for eventual developments in time study rating or pace comparison.

6. *Over-all implications in relation to Items 1, 2, 3, and 5.* The above mentioned conclusions seem to be applicable at all stages of learning. This indicates that there may be a basic motion characteristic for the activity which remains unchanged regardless of the curve characteristic indicators which are superimposed at earlier stages of learning. Therefore, once information about the additional curve indicators is obtained, this might provide a means for reducing the learning time on a job.

7. *Training Potentialities of Velocity Curves.* It is possible through a careful study and analysis of a set of velocity curves to obtain a clear picture of the motions which form these curves. During the course of the experiment a study was made of velocity curves obtained from an operator performing motions at random with speaker-frame apparatus. Many of the motions involved stops and starts not included in the experimental motion reported. A new subject was then instructed to perform one of the specific random motions which the analyst had studied. The new subject received directions for performance of the selected random motion in terms of accelerations, velocities, and decelerations. The resulting velocity curves of the new subject matched the original set indicating that training was facilitated by these instructions. The ability to describe completely the motions used in the performance of a job should greatly facilitate the entire training process since the proper performance of a job could be recorded on the UNOPAR tapes to be used in training new operators. A direct comparison between the trainee's performance at any time and the "correct" method can be made. The trainee can then be instructed on the areas where there is a difference between methods and in so doing a shorter training period should be reached as well as a greater certainty of similarity of methods.

Such records of methods will also be helpful in methods descriptions portions of time study.

Many other conclusions will be available from the data when complete data handling procedures are used. The basic data curves of acceleration-deceleration versus time, and displacement-position versus time will be available to obtain still further information.

QUANTITATIVE AND GRAPHIC CONCLUSIONS

1. From various graphical techniques and experimental data, it is apparent the operators learned this job within an extremely short period of time. Although this conclusion may have been drawn from ordinary "production" data on such a job, every other variable connected with the operation showed the same trend. This is a definite base for later experiments which can attempt to find more specific measurements highly correlated with output and learning.

2. Although one subject BK showed a high correlation with peak acceleration and deceleration (peak values and times), there were no high correlations for subject JB with any criteria (except possibly a slight correlation with one measure of peak velocity). This indicates there might be a possibility that peak acceleration and deceleration (rather than peak velocity) values are the most important factors related to output.

Two seemingly conflicting sets of results were obtained in relation to determining which factor, peak acceleration or deceleration, was more highly related to output. When relating time with acceleration time for subject BK, it appears that acceleration is more dominant in determining total time. However in relation to peak acceleration and deceleration values, peak deceleration was very slightly higher in its relationship with total time. Which is most important, or what is the proper combination of factors will have to be determined in future experiments. Such determination of factors affecting time for performing a job is important in development of an index of human performance.

3. From both quantitative (correlations of 02 with 19, 20, 21, and 22), and graphical data, it appears there is a constant percent of acceleration time and constant percent of deceleration time within a motion. This is true regardless of the stage of learning. For these experiments, it appears that 38% of the time is spent in deceleration and 62% in acceleration (subject JB had 62% for acceleration and BK 60.5%).

4. There was much evidence to show that motions are interdependent, and that one aspect of a motion is highly dependent on another aspect of another motion. For example, *forward* force 03 is highly correlated with peak acceleration and deceleration *backward*. Which is the cause and which is the effect is not known.

Subject JB had a fairly high correlation of peak velocity *back* with *forward* time; the peak velocity reached in the backward motion was highly correlated with the forward time. There were many other correlations which likewise indicated interdependence of motions. Time in acceleration backward 13 with peak deceleration forward 16, peak deceleration forward 16 with peak acceleration backward 17, and peak acceleration forward 15 peak deceleration backward 18 were highly correlated.

5. There was some indication of a downward trend in the learning process after the peak had been reached. This is shown

especially in Figures 3, 4, and 5. Even Figure 6 shows some of this. Future experiments will involve longer test periods to provide more information about "production" to help evaluate this downward trend.

6. A cyclic characteristic seems to be present in some learning curves, like Figures 5 and 7. Like conclusion 5, this is somewhat unusual, and may be an important characteristic of learning. This phenomenon will be investigated further by longer experimentation.

7. People are not able to perform identical motions in opposite directions with the same degree of facility. For example, backward motion was the most difficult to perform properly. The force was hard to keep within limits. This is shown by visual inspection of the curves, and by the correlation between backward force and run number. Likewise, Figure 4 shows an interesting contradiction. The front peak velocity decreases more rapidly than the back peak velocity after reaching the plateau peak. An attempt was made to find the relationship between good attempts forward and good attempts back, but mechanical difficulties in testing prevented this.

8. The peak velocity values (Fig. 4) for subject JB decreased slightly as the test progressed while the peak acceleration values (Fig. 6) stayed about the same. It is possible that the subject (subject BK did not show this relationship) had learned to make a greater utilization of the acceleration effort by not continuing in acceleration for as long a period of time as in earlier trials. Yet, the subject was achieving the same productive results (measured in terms of any of the criteria). In effect, it appears that the same peak acceleration was being achieved, but the rate of acceleration after reaching this peak decreased more rapidly with learning, thereby resulting in a lower peak velocity. One aspect of learning to be checked further may well be the *ability to make a greater utilization of the acceleration effort by* not *reaching as high a velocity in performing work after lengthy practice as reached in early trials.* Correlations between 02-05 and 02-06 indicate somewhat the same conclusion.

9. There was a significant interaction of peak velocity forward 05 and total time backward 09, and peak velocity backward 06 and total time forward 08 for subject JB, but not for subject BK. JB performed on the more difficult job (closer force limitations). A question therefore arises concerning performance time: Had JB not performed long enough or had BK performed "too long"? Such correlations, or lack of correlations, could possibly become true measures of learning. Even though the classical learning curves showed that a constant level of "production" had been reached, this phenomena may be an indicator of the acquisition of skill for BK, or an indication of inherent different levels of skill between operators.

REFERENCES

(1) Barnes, Ralph M., *Motion and Time Study*, 3rd ed., John Wiley and Sons, Inc., New York, 1949, p. 333.

(2) Deegan, W., "The Development and Use of a New Technique for Measurement in Time and Motion Study," M.S. Thesis, University of Iowa, Iowa City, 1935.

(3) Goldman, J. "Development and Testing of an Electronic Method for Determining Acceleration, Constant Velocity and Deceleration of Body Motions," Doctor of Science Dissertation, Washington University, St. Louis, Missouri, August, 1955.

(4) Lowry, S. M., Maynard, H. B., and Stegemerten, G. J., *Time and Motion Study*, McGraw-Hill Book Company, Inc., New York, 1940, p. 207.

(5) Mundel, M. E., *Motion and Time Study*, 2nd ed., Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p. 313.

(6) Nadler, G., *Motion and Time Study*, McGraw-Hill Book Company, Inc., 1955.

(7) Nadler, G., and Denholm, D. H., "Therblig Relationships: I—Added Cycle Work and Context Therblig Effects," *Journal of Industrial Engineering*, March-April, 1955, p. 3-4, 23.

(8) Nadler, G., and Goldman, J., "The UNOPAR," *Journal of Industrial Engineering*, January-February, 1958.

(9) Nadler, G., and Wilkes, J. W., "Studies in Relationships of Therbligs," *Advanced Management*, February, 1953, Vol. 18, No. 2, p. 20-22.

(10) Schutt, W. H., *Time Study Engineering*, McGraw-Hill Book Company, Inc., New York, 1943, p. 65.

(11) Segur, A. B., et al, *The Story of Motion Time Analysis*, A. B. Segur & Co., Oak Park, Illinois, p. 7.

(12) Woodworth, R. S., *Experimental Psychology*, Henry Holt, New York, 1947, p. 164.

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The Changing Aspect of Industrial Engineering*

by S. E. SCHARFF

District Supervisor of Industrial Engineering, Ernst & Ernst, Houston, Texas

DURING the first half of this century the productivity per man hour in American industry increased from 53 index units to 165 index units. It is estimated to have reached approximately 185 index units in 1957. In comparison with other countries American productivity is impressive. Taking our productivity in recent years at 100, Canada is the runner-up with a 73, while the next closest country shows about 40. (There are no reliable figures available for Iron Curtain countries.)

This productivity has been recognized abroad, and through intergovernmental agencies some 17,000 foreign technicians have come to this country since World War II to observe and study our factories and techniques. The report of such a visit made by a team representing the French Association for the Improvement of Productivity included the statement that, "In the United States productivity is a state of mind. It is the mentality of progress, of constantly improving what there is. It is the willingness not to be content with the present situation, however good it may be."

All of us are justifiably proud of this record and of comments from outsiders such as the one I have just quoted. However, our pride is dangerous in that it is difficult for us to be proud and dissatisfied at the same time; and dissatisfaction is one of the foundations of our progress as the French have noted.

In trying to balance our thinking between pride and dissatisfaction, perhaps taking a look at our position as 1958 model industrial specialists would be of interest. Just where do we stand in relation to the national economy today?

In a recent appraisal of the general economic outlook for this country for the next decade MacKay-Shields Associates, Inc., of New York, economic consultants, made some rather unusual statements. They were unusual for several reasons, but perhaps most because of their optimistic tone. This optimistic forecast stems from a number of basic situations, but predominant throughout the discussion is the emphasis placed on research and development, and the effect they have had (and will continue to have) on our economy. The belief is expressed that the doubling of expenditures for research and development during the past ten years has resulted in this nation being not in a single technological revolution, but in no less than sixteen separate, although interrelated, technological revolutions.

According to Mr. Shields, these sixteen technological revolutions are as follows:

1. A revolution in research itself, through utilizing new electronic and atomic tools and techniques.
2. A revolution in medical technology which, with increased birth rates, is causing a "population explosion."
3. A revolution in population redistribution to suburban and southern areas.
4. A revolution in income redistribution with great increases in middle income brackets and fewer poor people.
5. A revolution in techniques to handle clerical jobs.
6. A revolution in the production of power due to atomic developments.
7. A revolution in production techniques through electronic automation.
8. A revolution in distribution through new methods and devices.
9. A revolution in agriculture through chemical as well as mechanical developments.
10. A revolution in metallurgy as new metals and alloys become available.
11. A revolution in transportation as new engines, new fuels, new roads and new waterways come into use.
12. A revolution in communications as transistors and closed circuit television become prominent.
13. A revolution in education as we take advantage of closed circuit television and other techniques. (It is my personal hope that this revolution in education will include a return to the teaching of reading, writing and arithmetic to our children in grammar schools, and of mathematics and science in our high schools. This nation cannot survive if it does not.)
14. A revolution in the art of warfare through missiles, nuclear devices, etc.
15. A revolution in planning by government, business and finance through the use of statistical analyses of problems by electronic computing devices.
    (Please note carefully this 16th revolution.)
16. "A revolution in management techniques which are slowly evolving into a science, assuring that all of the other fifteen revolutions will be put to use by business to improve productivity and production."

Need I point out to you that "management techniques" and "to improve productivity and production" are

* Based upon a presentation to the Oklahoma City Chapter, AIIE, Cost Control Clinic, February 15, 1958.

phrases which are synonymous with Industrial Engineering?

This 16th revolution which is forecast after sound reasoning by an authority in the field of economics should be a challenge to each of us who is a member of the production team, and to Industrial Engineers in particular.

To determine just how much of a challenge this forecast presents to us and why it is important, let's ask ourselves a few questions and see if we can find answers to them. I have brought along with me a genuine crystal ball to assist us, and am in a position to bring into play an Ouija Board if necessary.

First Question: Why was it said that "management techniques are slowly evolving into a science?"

Until late in the last century management was a haphazard and individualistic entity which had developed "willy nilly" in the hundred odd years which had elapsed since the Industrial Revolution. Few of its principles had been codified, perhaps because it was predominantly unprincipled. The picture which comes down to us of those years is one of ruthless exploitation of the possibilities of the moment, with a blind trust in the manifest destiny of our nation and our economy to take care of the future.

It is difficult to reconcile such a picture with the origins of industrial organizations which we know today as enlightened and progressive companies which command the respect of the general public as well as of their customers and employees. Yet many such companies had their origins in those years.

Obviously a change occurred somewhere along the line. I believe that two factors were primarily responsible for that change:

1. An awakening social consciousness finally recognized the shameless exploitation of labor, and realized that labor organizations were not all monsters.
2. The advent of analytical thinking in relation to industrial problems.

It seems to be a characteristic of important discoveries and of significant new ideas that their inherent simplicity is astonishing—that is once discovered or stated. So it should not surprise us too much that it took over a hundred years for someone to decide that problems relating to the production of goods could be subjected to a reasoning, quantitative analysis somewhat akin to techniques used by engineers in dealing with problems not involving human beings.

So we find that there evolved from the turmoil and ferment of those early years three men who (rightly or wrongly) represent in our thoughts the three basic concepts in which the profession of Industrial Engineering found its origin. Those three men were:

Taylor, who represents to us "time," or how long it should take.
Gilbreth, who represents to us "method," or the best way to do it.
Gantt, who represents to us planning or scheduling.

Regardless of how simple in concepts or how crude in application, these three basic ideas were (in essence) the whole of Industrial Engineering for many years. With certain possible exceptions Industrial Engineering was (in essence) the whole of "modern management" during those years.

Taylor began his work in 1881. By 1912 the practitioners of Taylor's and similar techniques had brought them to such questionable repute as to warrant a Congressional investigation. At that time Taylor testified that his techniques were "scientific." We know that this was questioned by many. I can testify that as late as the early 1930's an Industrial Engineer had precious few techniques or refinements available to him other than the three basic concepts referred to above. I can also testify that, in those days, an Industrial Engineer was never quite sure of his status in society or in industry. He was somewhere between a knight in shining armor and the despised efficiency expert. Remnants of this questionable status are still found, but fortunately on fewer and fewer occasions.

Actually the past twenty years have produced perhaps 90% of the refinements, advances and new techniques in the management and Industrial Engineering fields. So, as a broad generality, we might say that it took us half a century to *start* bringing our profession out of its deservedly questionable beginnings and into some semblance of a scientific approach.

Is there any wonder that Mr. Shields says that "management techniques are *slowly* evolving into a science"?

Second Question: What has happened in the past twenty years to justify hopes that management techniques will actually qualify as "scientific" some day?

First, and perhaps most important, we have recognized that our techniques and methods are not scientific, and an increasing number of us are acquiring the guts to stand up on our hind legs and admit it.

Second, research is nibbling away at unscientific features and is gradually reducing the element of judgment involved in so much that we do.

Third, we are using mathematical tools which have been available for years, but which we were regrettably slow in adapting to our use.

Fourth, new concepts and ideas are occurring with increasing frequency as a result of more people with better education and background consciously and with malice aforethought searching for them. This is another aspect of research.

Fifth, we are borrowing concepts and ideas from other sciences or professions and adapting them to our uses.

Sixth, practitioners are recognizing that the strange products of the academic world are not the playthings of pale-faced scholars, but that a large portion of those products can be used to advantage in practical applications.

Dean David of the Harvard Graduate School of Business Administration once stated, "Usually some label of academic calm or ivied walls or ivory towers is put

on those who work in universities. I sometimes think there are today more ivory towers in the business community than in the universities. Far too many businessmen have secluded themselves with their own groups without opening their minds to what is happening. . . ."

That puts the monkey on our back, but I must admit that I cannot help but agree with him.

Along this same line, it is interesting to us old timers to recognize the difference between the present attitude of business and industry as a whole towards a college education and that same attitude twenty-five or thirty years ago.

In those days a young engineer was pretty apt to be told to forget his highfalutin education and get some "practical" experience. Those days are gone and with them most of the thinking which looked upon higher learning as a frill, regardless of whether it was acquired in a university or at night alone and at home.

There are a number of reasons for this change. So many more people of all economic groups of society are acquiring higher learning that it has lost its "class stigma" and thereby is more readily palatable to some people. However, the plain and indisputable fact is that people who have become educated—regardless of how or where—have out-performed the so-called "practical" man by so wide a margin and in so many instances that there remains no serious question of supremacy.

I dislike using the words "scientific" and "practical" in a contrasting sense, because science is as practical as anything can possibly be. It is only the impractical who have been unsuccessful in adapting science to practical use. However, in the accepted lingo of a few years ago the educated man has beaten the "practical" man by being more nearly scientific in his approach and practice. But, let's be a little more specific for a change, and cite a few examples of what is recent or new in application and in research.

A number of people are trying to relate elemental times to basic motions, and to produce standard data more accurate and more nearly universal in its applicability. Several "systems" of such data are in use today and are being refined and improved almost constantly, through use and through research.

At least one group is doing basic research on the exact nature of body motions. They are measuring velocities, acceleration, deceleration, etc., using the Dopler effect as the means of translating those motions into readily measurable entities.

Adaptations of statistical techniques are becoming commonplace. Statistics offer one of the most readily available sources of refinement and original thinking. Adaptations include work sampling, quality control and numerous others. Research continues on the range of human capabilities. Statistical and other mathematical and analytical approaches have resulted in such techniques as operations research with attendant tools including queueing theory, theory of games, linear programming, Monte Carlo, model making, gaming and other devices used in solving management problems. The very names of these devices are still strange to many of us.

The list is long, so let's let it stand as it is. However, we should realize that each of these named (and many unnamed) is a device which we can use to arrive at a better, more nearly scientific, answer to some problem which would have gone unanswered or half-way answered 10 or 20 years ago. We *are* making progress toward becoming scientific!

Third Question: How are we failing to keep pace with these developments, and what, in general, is our primary shortcoming?

I do not know that we *are* failing to keep pace with these developments. The recent growth of technical societies and the interest displayed in published literature is evidence to the contrary. Your presence at this splendid clinic is evidence to the contrary. (Incidentally, I would like to commend to your attention the *Journal of Industrial Engineering*. During the past two or three years it has developed into a publication of which AIIE can be proud and which is an excellent source of information on new developments.)

We may, however, be failing to do all that we can to further the cause. I think our greatest failing is in not keeping our superiors (and in particular, top management) appraised of new possibilities, and in not educating them to use what is new. Too often the impetus is not from us, but from the top as a result of "the boss" having read an article in some journal of business or finance. Even when we are well informed of new developments, we are pretty poor salesmen in too many instances.

As to our primary shortcoming, I believe it lies in the imaginary boundaries we ourselves have used to circumscribe our sphere of operations. We think of ourselves too often as limited to matters pertaining to direct labor and the production of goods. As examples, matters pertaining to the production of clerical records would be beneath our dignity, or matters pertaining to indirect labor are the problem of the plant engineer, not ours. Yet each of these two items is consuming an increasing portion of the sales dollar, year after year.

In the past fifty years the ratio of clerical employees to productive employees has increased ten fold, and the ratio is getting worse all the time, in spite of the high degree of automation already available. How many of us realize that our techniques are directly applicable in this field? And of those who realize it, how many are willing to do something about it within their respective companies?

In these days of increasing automation indirect labor is increasing rapidly (particularly in maintenance personnel) while direct labor is decreasing. In the process

industries where automation is relatively advanced, maintenance crews are nearly as large as operating crews now, and in the near future will be larger than the operating crews. How many of us have recognized this and are doing something about it within our respective companies?

Too often we have failed to pick up the challenge of *being* management instead of working for management. We must realize that a modern business is so complex and its components so closely interrelated that the carving out of a single segment as our sphere of operations is dangerous and unjust to ourselves and to the business itself.

To do this we must not only keep pace with new developments in our own and related fields, but we must also acquire a better knowledge of the fields and problems of the other members of the management team.

How many of us know the problem of, or stand ready to help, the top sales executive of our company? How many of us realize that nine out of ten of us have at our fingertips knowledge and techniques which could help him tremendously? How many of us realize that the answers he is searching for will materially affect our work on the production floor?

How many of us know the problems of, or stand ready to help, the top financial executive of our company? The Controller? Yet they could use our help, and their decisions may well have a material effect on our own work on the production floor.

How many of us know the problems of the chief accountant or cost accountant? How many of us realize how closely related our own activities are to those of the cost accountant, particularly if our company has a standard cost accounting system?

How many of us share the problems of the personnel manager, or realize how closely they relate to our own problems?

My experience has been that the answers to these questions are unfavorable in far too many instances.

And so our challenge in this 16th revolution is a three-fold challenge:

First, to jealously guard and foster dissatisfaction.

Second, to learn and to use each new development or technique to insure that our work is the best that can be done.

Third, to erase the imaginary boundaries that surround us and to apply our abilities in areas we have shunned in the past.

If we fail to pick up this challenge I can assure you that some other group will do so. I feel sure that you realize that the sole requirement for founding a new profession today is to concoct a new jargon, so don't bother wondering which group might pick it up if we don't.

But if we do pick up this challenge we will find that we are welcomed to the councils of the great; and almost before we know it, we will have become an indispensible part of the management team.

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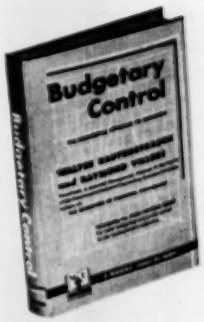

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Waiting-Line Models in Materials Handling[1]

by **ROBERT B. FETTER**

Assistant Professor of Industrial Management, Massachusetts Institute of Technology

and **HERBERT P. GALLIHER**

Assistant Director, Operations Research Project, Massachusetts Institute of Technology

THE OBJECT of this paper is to give an expository treatment of the application of "waiting-line" models in determining the least-cost number and type of materials-handling facilities to provide in a given operation. Because individual materials-handling requirements vary so much from one situation to another, only general principles can be treated, and illustrations given with what may seem to be relatively artificial situations.

Our chief interest is to indicate that waiting-line analyses of the materials-handling function in production yield more realistic measurements of the effects on total production rate and costs of a characteristic but evasive phenomenon of all production. This phenomenon is that of the *cumulative effect of random delays,* in this case delays in handling materials. By radom delays is meant no more than the familiar ones which always occur during a shift or day due to randomly spaced requests for goods to be moved, or to variations in the time required to perform jobs.

The cumulative effect of such delays, which can be viewed as random variation in production flow, is difficult to measure short of utilizing the rather sophisticated mathematical statistics of waiting-line theory. This theory has, however, had application elsewhere in Industrial Engineering, notably in textile mill operation and in telephone engineering, the latter field having pioneered its development. In this paper, the mathematical methods shall be avoided and concentration made on approach and problem formulation. A substantial technical literature is available to the interested reader, some of which will be found in the list of references.

As a focus for discussion, the operation of material-handling units to transport goods between producing centers in a factory has been chosen. In the discussion, the decision as to types and number of units to provide and the consequent average delays predicted by waiting-line formulations is related to the basic economic considerations of least over-all production cost.

[1] The research underlying this paper has been supported in part by the Army Office of Ordnance Research under contract DA-19-020-ORD-2684, at M.I.T. and in part by the Sloan Research Fund of the School of Industrial Management, M.I.T.

OPERATION OF MATERIALS-HANDLING CREWS

The problem envisaged here occurs typically in a fairly large job-shop. A considerable volume of materials and partially finished work must be transported continually from some department to another. Usually this work is the responsibility of a materials-handling department, staffed with the crews and equipment necessary, which receives calls from many producing centers to render service for a variety of moving jobs arising during a day's activities.

In such an operation the assumed objective of the materials-handling effort is to move materials at least cost, considering the cost consequences both of delays and of investment in moving facilities. In some cases advanced scheduling of moves is possible. However, the problem of interest here is the not infrequent case in which, due to the very size, complexity and activity of the plant, calls for materials-handling units cannot be predicted much in advance, if at all. Instead, these calls occur in some random fashion, steady in average rate, but at any given time exhibiting considerable variability in frequency of occurrence and in kind of service requested. Thus, the materials-handling facilities may be swamped at one time and idle soon after.

The result is a kind of congestion problem, in which it is no longer easy to predict the least-cost materials-handling capacity to provide. Delays in movement due to insufficient handling capacity mean an increase in the amount of in-process inventory associated with a given outflow of finished goods. Too large a capacity on the other hand, in addition to getting in its own way, will not pay off in a commensurate reduction in delay.

The use of waiting-line models to determine the optimum *balance* between cost of facilities and cost of delay represents a sophisticated but practicable and effective approach. The sophistication may be illustrated in terms of a single lift truck whose average moving task takes 15 minutes, though the time required varies in a random fashion from one job to the next. Table 1 displays the resulting delays and the net average percentage of time the truck is busy for various "loadings" measured in average number of calls for work per 15 minutes. Some assumptions are made here concerning the kind of prob-

TABLE 1

Delays and Idle Time for a Single Unit with Various Loadings

Loading, in calls per 15 minutes	Average % of time truck is idle	Average delay, in hours, of goods to be moved
.1	90	.03
.5	50	.25
.8	20	1.0
.9	10	2.25
.95	5	4.75
.99	1	24.75
1.00	0	Infinite!

(The assumptions underlying this table are that calls are distributed according to a Poisson distribution and service times according to an exponential. These distributions are discussed in the article.)

ability distribution which describes calling and servicing intervals. These will be explained later and an indication given of the kinds of probability distributions which may be anticipated in various operational situations and which may be readily utilized in the mathematical calculation of the waiting-line formulations.

It can be seen from Table 1 that if delays are to be kept below 15 minutes per call on the average, the truck must be idle half the time. On the other hand, if the trucks are kept nearly always busy, the average delay is quite large. These paradoxical comments do not exaggerate the consequences which must be faced in a congestion situation. Rather, they stress the need for explicit balancing of costs. A truck crew which is almost always idle may by no means be uneconomic if there are compensations in terms of reductions in delay.

THE ECONOMIC PROBLEM

The basic economic problem is one of determining the amount of materials-handling capacity to provide. The cost of additional handling facilities must be balanced against alternative costs incurred by delays in movement. Whenever there is any variability present in such situations, then delay will occur if when a call arrives all handling facilities are busy with prior calls. This delay could have been avoided if more handling units were available. There is, therefore, some optimum level of facilities at which the cost of additional handling facilities is just balanced by the delay cost saved.

The cost of additional handling facilities is made up generally of two parts: 1. a fixed cost occasioned by investment in physical equipment, and 2. variable expenses, primarily those due to labor and maintenance.

FIXED COST

Any costs which will be incurred whether the handling units are operated or not should be included in the fixed cost category, while those associated with operation should be included as variable costs. The fixed cost is necessary in order to determine the optimum investment in handling units. For example, if the average volume of movements changes due to changes in production level from shift to shift or seasonally month to month, the cost of delay would be computed for each possible set of facilities and the optimum set established by balancing this cost against the fixed cost associated with each set. Then, given this set of facilities, the optimum operational level (number to man) as the volume of movements changes can be established by balancing the cost of delay versus the variable cost of operating additional trucks.

COST OF DELAY

The cost of delay is somewhat more difficult to determine than is the investment cost. For this reason it is apt to be overlooked. It is often expressed in several forms, one of which is extra costs of expediting and supervision, and another, loss of production.

A subtle but potentially appreciable component of the cost of delay is that occasioned by the *additional in-process inventory* which results from delay. This cost is equivalent to a reduction in turnover, and an increased cycle time for producing any given lot of finished goods. To illustrate this, suppose that a given job must pass through a number of departments in the course of production, and that it must be "handled" in going from one department to the next. Its total production time, from start to finish, is the sum of the processing, or job, times in the departments *plus* the handling times. If these handling times include a delay, then a simple algebraic analysis will show that if

$$d = \frac{\text{average delay per job}}{\text{average production time per job if no delay occurs}}$$

then the ratio of net flow (including delays) of finished goods, to capacity flow (without delay) is

$$r = \frac{1}{1 + d}$$

= fraction of turnover capacity actually achieved

This last is the fraction of the capacity rate achieved with some given set of facilities. As facilities are increased (and, therefore, d decreased), this fraction approaches unity, but only of course at an increasing cost.

Since costs of idle personnel, lost production and extra in-process inventory are usually known on a unit basis, there is no great difficulty in costing a given delay. Rather, the problem is to measure the incidence of delays and to determine their magnitude.

It is in the measurement and correct prediction of these delays that a waiting-line approach is of special utility. Calls for handling will always occur in a random way, in spite of efforts to schedule them; this is no more than a universal comment about attempts to schedule anything. Some delays will consequently always occur. However, because of the complex effects of random accumulations of calls, the prediction of the size of delay is not easy to accomplish in a thorough way without resort to waiting-line models.

Accordingly, we turn now to a discussion of the basic concepts and terminology of waiting-lines.

WAITING LINES

The conceptualization here is that there is a servicing-point, at which units of some sort are arriving individually to receive service. Arrivals are not necessarily evenly spaced in time, nor their exact arrival times known in advance. At the servicing point there may be one or more servers (or service-stations) available to handle the arrivals. Individual servicings do not always take the same amount of time, nor are these times wholly predictable. The variable spacing in time both of arrivals, and of servicing are described by saying that they are *random*.

Because of this randomness, arriving units are from time to time forced to wait, and the group waiting is called the waiting line or *queue*. Time spent in the queue is called the waiting time, or the *delay*. Calculation of this delay is a major concern of the mathematical analysis of a waiting-line.

Daily experience affords many familiar examples of waiting-lines: banks, restaurants, highway intersections, repair shops, the in-box on an office desk. A less obvious example is the operation of a telephone exchange. Much of the mathematical theory now available to analyze waiting-lines has been built up over the past 50 years by telephone companies around the world (10). Additional contributions have come from Industrial Engineering in connection with the manning of semi-automatic machines in textile plants (7) (8).

In applying the basic conceptualization above to materials-handling, obviously, the "arriving units" are goods to be moved. The servicing-point may not necessarily be a point at which the goods arrive physically; it might, for example, be a central dispatch station at which *calls* for servers are received and servers dispatched. (In the conveyor model to be discussed later, the servicing point will be the discharge end of the conveyor.) The servers are clearly the handling-units or crews, and the servicing is the task of moving the goods. The delay is not the movement time, which is inescapable, but rather the potentially unnecessary wait until a handling unit arrives to pick up the goods.

RANDOMNESS OF CALLS

Let us next discuss the features connected with the randomness of arrivals, or as we shall term them, "calls." First, by *calling rate,* is meant the *average* number of requests per unit time, for goods to be moved. The mathematical approach of waiting-line theory is statistical, and consequently considerable variability of individual calls is tolerated even though the average rate is a constant.

This average rate is to be associated with the average production rate, over a period even of months, of the production centers initiating the calls. The period to be chosen for averaging the rate is just that for which a definite allocation of handling facilities is being made. If multi-shift operation is the case, with production rate characteristically different on the separate shifts, the number of physical handling units, such as trucks, will be related to the maximum rate on any shift, although the number of crews scheduled to be available to man these units may be varied to fit a rate which is characteristically lower on certain shifts.

Within the period of constant average calling rate, the frequency of individual calls will vary in a random way. This variation is described by the *probability distribution* of calls. An illustrative distribution of calls received in the course of a one-hour period at a central dispatch point is portrayed in Figure 1. Note that although the average is 10, in less than 15 out of 100 one-hour periods will 10 calls be received.

The type of probability distribution which can be expected in any particular materials-handling situation will depend upon the situation itself. Both statistical and operational validity should be checked before preferring any distribution to another. However, there is one special distribution, known as the *Poisson* distribution, which is quite apt to characterize calls in a complex materials-handling operation such as the dispatch office in a large plant (indeed this distribution has found widespread application in machinery breakdown, in telephone traffic, in truck arrivals and in other operations which are thereby revealed to be similar in the occurrence of calls for service).

When this kind of distribution holds, the mathematical formula for the probability $p(n;T)$ that n calls will be received in a period of time T

$$p(n;T) = \frac{(\lambda T)^{n} e^{-\lambda T}}{n!}, \qquad n = 0, 1, 2, \cdots$$

where λ is the calling rate per unit time. A typical plot

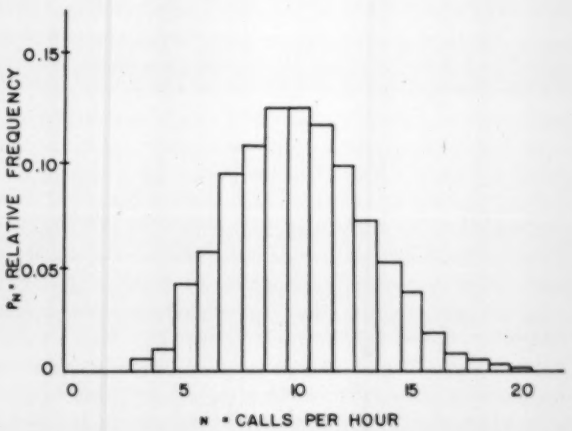

FIG. 1. Frequency distribution of calls for Handling Service

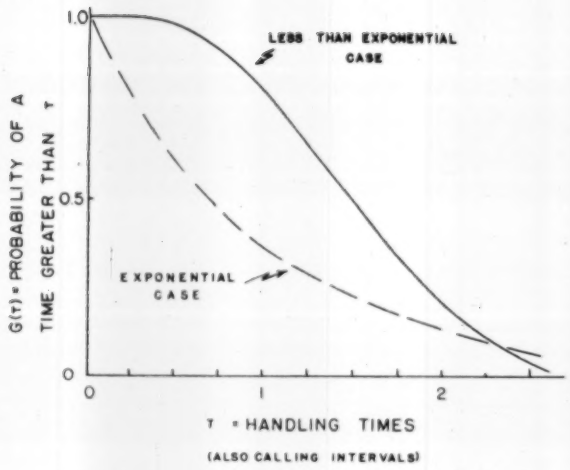

FIG. 2. Schematic Distribution of Handling Times or Calling Intervals

of this distribution is given in Figure 1. A detailed discussion of the properties of this distribution can be found in many textbooks on probability, for example (5).

When it comes to gathering data on arrivals of calls, a corresponding notion of greater utility is that of the *calling interval*, which is the time interval between successive calls. This is, of course, a continuous-time quantity. It will have a probability distribution of the sort illustrated in Figure 2. In the case of "Poisson" calls, the distribution of the calling interval will be exponential in form (and therefore linear on semi-log paper). That is, the probability p(T) that between two successive calls a time greater than T elapses is given by

$$p(T) = e^{-\lambda T}$$

where again λ is the calling rate per unit time. A plot of a distribution of this type is given by the dashed-line in Figure 2.

HANDLING-TIMES

In order to separate out delay times, handling times must be carefully defined. Basically, by such a time is meant the interval from the moment a handling unit is assigned to move a certain load until it is ready to be assigned to move another load. When units are centrally dispatched, handling time begins with the moment of dispatch and terminates when the unit reports back.

The same considerations about average times and randomness of individual times apply here as in the case of calling intervals. Averaging is to be done over the interval for which handling facilities are to be permanently acquired. Randomness of individual calls is described in terms of the probability distributions of their lengths. These lengths must therefore be observed by sampling measurements in order to construct this probability distribution.

NECESSITY FOR MEASURING PROBABILITY DISTRIBUTIONS

In data-gathering, many people are prone to make a number of measurements, average them, and then ignore the dispersion of the individual measurements from the average. In waiting-line models the dispersion is, however, of major importance. To illustrate this, let us take for simplicity an example involving a single server. When calls are "Poisson" it is known that the probability P_0 that the server is idle is

$$P_0 = 1 - \lambda h$$

where λ is the calling rate, and h the average servicing (handling) time. That is, P_0 depends only on *averages*. However, the mean *delay* time W is known to be (9) (11)

$$W = \frac{(1 - P_0)}{2P_0}(1 + c^2)$$

where c is the *coefficient* of *variation* of the handling time, that is

$$c = \frac{\text{standard deviation of handling time}}{\text{average handling time}}$$

Here W is given in units of the holding time. Thus, delay is a direct function of the *variability* of the handling times, and can be increased by any given amount by increasing that variability sufficiently even while average handling time remains the same. The variation of W with c is plotted in Figure 3 in terms of the value of W when $c = 0$. Note that $c = 0$ corresponds to the case where handling time is constant; W is then a mini-

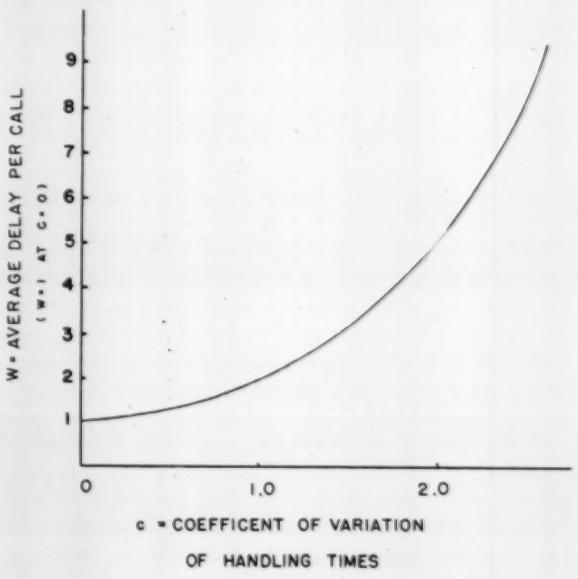

FIG. 3. Increase of Average Delay with Variability of Individual Handling Times. "c" is the Coefficient of Variation of the Handling Times.

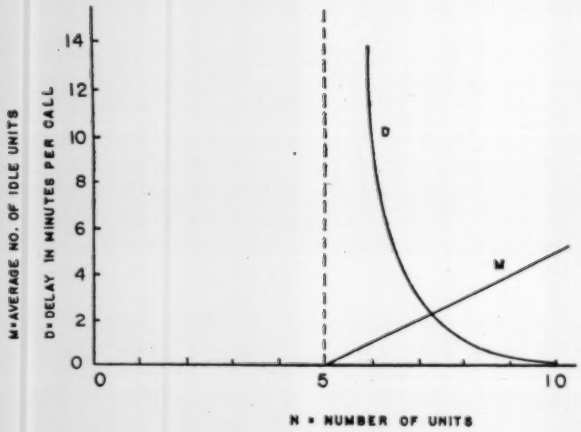

FIG. 4. Average Delay and Number of Idle Units for Various Service Levels.

mum. Thus, any variability in handling times results in a greater delay.

HANDLING DISCIPLINE

By handling discipline is meant the routine procedure for assigning handling units to calls. The discipline may be first-come-first-served in a central dispatching arrangement. In addition, a certain proportion of the calls may be given priority over other calls. There may be special purpose units for handling heavy, fragile or otherwise special jobs, including gang service obtained by grouping crews and units to handle a large task.

On the other hand, the discipline may be random, as when handling units patrol the plant, taking jobs as they encounter them. Each type of discipline is characterized by an average delay, which will in general vary with the discipline employed. Consequently, consideration of the type of handling discipline to employ is an important part of the search for a least-cost solution to the general problem.

ILLUSTRATIONS

The details of solving mathematically the equations that arise in a waiting-line formulation of materials-handling and other production-flow congestion problems are not included here. Later, in discussing the approach which an Industrial Engineer should plan in tackling an actual application, references will be given where these details may be found.

Rather, two illustrations will be given of the kinds of results that can be predicted in certain cases. In both illustrations it will be assumed that the arrival of calls is characterized by a Poisson distribution and that handling-time has an exponential distribution with successive times statistically independent. As to the validity of these assumptions in any particular case, nothing can, of course, be said without inspecting actual data. These distributions were chosen for the illustrations partly because numerical results were readily available for them,[2] and partly because in many applications the presence of these distributions is the first one which should be suspected.

A. RELATIONSHIP BETWEEN AVERAGE DELAY AND NUMBER OF IDLE SERVERS

A large job shop, with identical multi-purpose handling units centrally dispatched to answer calls in order of arrival constitutes an especially simple waiting-line situation. The basic economic problem is taken to be "what is the optimum number of units to provide?" Therefore, a direct comparison is desired of average delay and average idle time for the handling units provided.

In Figure 4 this comparison is made for a numerically hypothetical case in which the calling rate is 15 calls per hour and individual handling times average 20 minutes. The plot illustrates the general features of any specific numerical case:[3]

First, 5 units are completely insufficient, the average delay being "infinite." The general principle involved here is a fundamental one in all waiting-lines, namely that in order to keep the average delay finite, it must be true that

(calling rate) $\times$ (average holding time) $<$ number of servers

(Not even a "$\leq$" sign can be tolerated.)

Second, the amount by which delay is reduced by adding servers decreases in a non-linear way as the number of servers added increases. Consequently, there will be some optimum number of servers if the cost of idle facilities is proportional to idle time, and the cost of delay proportional to average delay.

Effect on in-process inventory. Suppose that in this illustration each unit of material receives a 3-hour processing time at the next producing center to which it is moved. Then its total time per move-cycle, namely

processing-time + delay + handling-time

will be

180 minutes + delay + 20 minutes

Comparing, for example, the advantages of having 7 handling units, it can be seen from Figure 4 that the corresponding delays are approximately 3 and 9 minutes.

The addition of *one* extra unit from the 6-unit level of operation means therefore an increase in turnover, and a reduction in in-process inventory, of approximately 4% (180 + 12 + 20 vs. 180 + 4 + 20). In an actual applica-

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[2] The numerical values were taken from a volume of tables of waiting-line probabilities currently under preparation at M.I.T. under the direction of Dr. Calliher.

[3] The calculations upon which figure 4 is based may be made using formulas available in (1), (3) or (6). Results for these same assumptions are tabled in (1) and (6).

tion, the corresponding change in cost would be obtained from a specification of the cost of additional in-process inventory and of idle units.

B. GENERAL-PURPOSE VS. SPECIAL-PURPOSE UNITS

Suppose that in the type of operational situation discussed in (A), some of the calls require a type of service which only certain handling-units are qualified to give. This is often the actual case and in attempting to cover requirements of this sort in the discussion here, one might visualize all sorts of complex specifications as to capacities of handling units and frequency of call for them. A basic question would be, "What reduction in delay is achieved by having general purpose units?"

For illustrative purposes, suppose that calls are divided evenly among 6 different kinds of jobs, with 2.5 calls per hour for each. Assume that each job takes the same average time as before, namely 20 minutes. To illustrate the effect of versatility in handling units, consider four alternative schemes. Since there are 6 different types of jobs, number them 1 to 6. Now one strategy would be to have all units similar, i.e., general purpose, and capable of handling only one type of call.

As alternatives to these a comparison of two additional strategies, namely two different types of handling units, with three identical units of each type, and three different types of handling units, with two identical units of each type. Units of different types are assumed to be incapable of handling calls of the same type, and it is assumed that call types are allotted to unit types so as to equalize the work loads of each type.

The results are portrayed in Table 2, from the bottom row of which it will be seen how great is the increase in delay if only special purpose units are available.

PRACTICAL CONSIDERATIONS

In the selection of illustrations and in the discussion so far, the intent has been to suggest rather than to codify. The basic thesis has been that the cumulative effect of delays in production such as occasioned by materials-handling is a complex statistical phenomenon, but one which can be formulated in the mathematics of waiting-line theory. A proper question at this point is "what are the practical consequences in considering whether to apply a waiting-line model to a particular materials-handling situation?

There are four main phases of such a project as follows: *operational description, data gathering, mathematical solution,* and *experimentation.* These are discussed briefly in turn.

TABLE 2

Number of unit-types	1	2	3	6
	Number of units of each type assigned to			
Job-type				
1	6	3	2	1
2				1
3			2	1
4				1
5		3	2	1
6				1
Delay per call, in minutes	12	28	46	93

(These values may be obtained from tables available in (1) and (6).)

OPERATIONAL DESCRIPTION

The best operational description is probably a flow chart, showing 1. sources of calls, 2. percentages of each type of such calls requiring service of a special type or special destinations, 3. unit-handling types presently available, and 4. alternative dispatching procedures available. Of course, the feasibility of operational alternatives should be explored in order that the technical description allow for a comparison of economic alternatives.

DATA GATHERING

The ultimate mathematical waiting-line model to be used will employ assumptions about the probability distributions of calling intervals and handling times. Consequently, data on these times must be gathered with this in mind.

Times must be observed on a sampling basis which allows for appropriate stratification. There may be a different distribution of calling intervals for each department, or of handling times for certain categories of calls, as for example priority vs. non-priority. When all units are multi-purpose for example, all calls may be aggregated into a single probability distribution of handling times.

For planning purposes, data on calling rate and handling times should be related to the production rate in the several departments. This is one way of treating problems imposed by seasonal variation in production rate, and characteristic differences between shifts.

MATHEMATICAL SOLUTION

The general mathematical formulation of a waiting-line problem is simply a set of equations relating the probabilities that at any moment some calls will be waiting for service, some in process, and some serving units busy or idle. While the formulation of these equations is not difficult, it is too long a subject to deal with here. Ample illustrations are available in the references cited, particularly (3) and (5).

Advantage should be taken of solutions to special problems already known and published. The following is a summary of many of the useful cases which have been treated:

1. Small shop operations—the problem here is analogous to the

assignment of operators to automatic machines (4). Tables are available for this case.

2. Large shop operations—here the calling population is large and calls are independent of one another. Tables of the relevant probabilities, queue sizes, and delays for a variety of handling time distributions are currently in preparation (see an earlier footnote).
3. Priority calls—the use of priorities to expedite servicing has been studied by various authors in articles in the *Journal of the Operations Research Society of America* (2).
4. Random servicing order—this problem is of interest to the telephone companies in determining delays experienced by telephone users (10).

One particularly useful technique for obtaining numerical results in cases where straightforward solution of the equations is difficult is a method known as *Monte Carlo Simulation*. Indeed this method may be applied in any problem at all, and for this reason has considerable utility. Its chief shortcoming is occasional uncertainty as to the reliability of results due to the fact that it is a statistical-sampling method.

Basically, in a simulation one simply operates the materials-handling effort on paper exactly as it would operate in practice. Beginning at a certain time, the actual value of a calling interval is chosen at random from the probability distribution of these intervals, a unit is assigned and a handling-time selected at random from the appropriate probability distribution. Meanwhile, the length of the next calling interval is chosen again at random and the "clock" advanced until either the first unit finishes or the new call arrives, whichever is first, and so forth.

In such a detailed "play by play" of the game, a record is kept of the delays experienced, of duration of unit idle times, and any other pertinent facts desired, from which the desired averages are easily tabulated. The play is carried on for a sufficient period to allow these averages to stabilize numerically (subject to an error of statistical estimation which decreases, occasionally slowly, with the length of play).

Simulations, sometimes referred to as "operational gaming" can be performed by hand. Some manufacturers of large-scale computers, and other groups active in the use of computers, have developed computer routines for simulation. A basic requirement here is to have a supply of random numbers. Tables of these are fairly plentiful (1).

EXPERIMENTATION

No solution proposed as a result of a waiting-line approach (or other theoretical approach for that matter) could be regarded as acceptable without some experimental testing. This phase, often neglected, is not always easy to perform, since it may require a major alteration of existing procedures.

It should be noted that *simulation* is often a suitable substitute for an experimental test, and in the authors' experience is the more so as it is thorough and realistic in every detail.

SUMMARY

While attention here has been focused on a centrally operated materials-handling function, there are other materials-handling situations which exhibit analogous features. A very obvious one is the operation of shipping terminals, as for example, a truck-loading platform. In that case both platform size and number of handling crews is the economic problem of concern. Still another application is the operation of a slip-feed conveyor. Due to random interruptions in loadings and unloadings, a slip-feed conveyor acts as a storage well for goods in transit. When the conveyor is full, loading must be interrupted until space is available for the unit to be loaded. Thus, one has a finite waiting-line in which the penalty is exceeding the maximum length of line.

It does not need to be emphasized that the problem in materials handling is one of congestion, and that due to the variety of work handled, a statistical approach is practicable. Waiting line models are specifically designed to handle such situations. The solutions which are available currently will cover many cases when the physical situation is relatively simple. When such solutions are not available in particular cases, simulation may be used to get estimates of the variables of interest (1).

REFERENCES

(1) Bowman, Edward H., and Fetter, Robert B., *Analysis for Production Management*, Richard D. Irwin, Inc., Homewood, Illinois, 1957 (Chapter 11).

(2) Cobham, Alan, "Priority Assignments in Waiting Line Problems," *Operations Research*, February, 1954, p. 70-76.

(3) Feller, William, *An Introduction to Probability Theory and Its Applications*, 2nd edition, John Wiley and Sons, Inc., New York, 1957 (Chapter 17).

(4) Fetter, Robert B., "The Assignment of Operators to Service Automatic Machines," *Journal of Industrial Engineering*, September-October, 1955.

(5) Fry, T. C., *Probability and Its Engineering Uses*, Van Nostrand, New York, 1928.

(6) Morse, Philip M., *Queues, Inventories, and Maintenance*, John Wiley and Sons, Inc., 1958.

(7) Palm, Conny, "The Distribution of Repairmen in Servicing Automatic Machines," *Industritidningen Norden*, Vol. 75 (1947), p. 75-80, 90-94, 119-123.

(8) Palm, Docent Conny, "The Assignment of Workers in Servicing Automatic Machines," *Journal of Industrial Engineering*, January-February, 1958.

(9) Pollaczek, F., "Sur une Generalisation de la Theorie des Attentes," *C. R. Acad. Sci.*, Paris, Vol. 236 (1953), p. 578-580.

(10) Riordan, John, "Delay Curves for Calls Served at Random," *Bell System Technical Journal*, Vol. 32, 1953, p. 100.

(11) Saaty, Thomas L., "Resume of Useful Formulas in Queuing Theory," *Operations Research*, Vol. 5 (1957), No. 2, p. 161-200.

How to Set Up Proper Budgets

by **PHIL CARROLL***

Professional Engineer

BUDGETS are set up in many companies to help in the control of costs. Some managers use them to try and look ahead by forecasting. Such forecasts are built up from projected sales. Thus, budgets may be set up for an expected volume of business, then later for the actual output in production and in sales.

To determine expenses for differing volumes, you need what are called "flexible budgets." These are based upon the relations between costs and volumes. To find these, the easiest way, perhaps, is to plot curves of historical expenses.

Expense trend lines will be mostly of the type called "semivariable" by accountants. That means you will find nearly every expense consists of a constant plus a variable. An engineer would think in terms of Budget $(Y) = b + mx$.

WHAT MEASURES VOLUME

To set up such expense trend lines, you have to be careful what you use to measure volume. Watch out if you use sales dollars. Remember, a dollar today isn't the same as a dollar tomorrow. Disregarding inflation, let me illustrate. Suppose the central point of your expense plottings represents normal times when you may sell a sales dollar for a $1.00. When demand is greater than normal, meaning larger volume, you sell a dollar for $1.05 or $1.10. Later, should business go into a "recession," you sell a dollar for $.95 or $.90.

The same thing happens with man-hours and labor dollars. When you expand volume, your man hour efficiency drops because you hire new people. When you contract, it goes up. These changes in yardsticks of your volume scale will tilt your expense trend lines. Above normal volume, inflation moves your plotted points horizontally to the right further than they should be. Below normal, your points will be further to the left in the ratio of, for example, $.90 to $1.00 of sales price. The result is to turn your trend line about normal volume as a center to raise the constant cost and lower the slope of your expense trend lines. This tendency is shown by Fig. 1.

The only reliable measure of output I know is standard time and that only when it represents good salable pieces. If you do not have standard times, then try to guesstimate them. One way is to build up volume measures by using the times equivalent to standard labor costs. Another is to adjust labor hours by percentages representing changes in productivity. Be sure to deflate for such waiting time and indirect time as may be included.

Having obtained your volume measure, you set up curve sheets. You may need 100 to 200. I make them on a production basis. I set up the horizontal volume scale in ditto typing and run off a quantity. On this scale, I mark the years at their corresponding volumes to save the counting off.

ARRANGE EXPENSES

The years just mentioned are determined by several factors. Primarily, what you want are those having the widest range in volumes from low to high. Obviously, the farthest apart you can get your plotted points, the more correct will be your trend lines. Correctness is also related to number and so I suggest at least five years of expenses.

Next you get the expenses for those years. Here the fun begins. You must collect them together in terms of the current responsibilities. The way I illustrate is to say in 1951 the Timestudy Department reported to Joe Black. In 1953 we reorganized and moved it under John Jones. This year, we plan to rearrange responsibilities

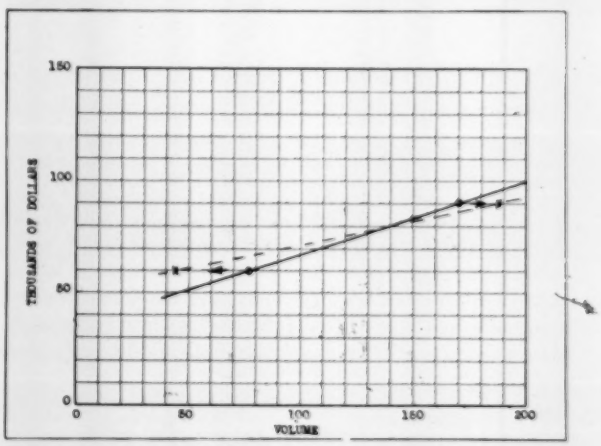

FIG. 1. (Your apparent volume changes from actual in times of expansion and contraction.)

* Author of McGraw-Hill books, *Timestudy for Cost Control, How to Chart Timestudy Data, Timestudy Fundamentals for Foremen, How Foremen Can Control Costs, How to Control Production Costs and Better Wage Incentives.*

and have it report to Dick Smith. That sort of changing happens in all organizations many times.

So the next step is to arrange the year's expenses rearranged in terms of your present organizational accountabilities. The important thing, later in the control of expense, is to tell Dick Smith that he's responsible for the budget you work out.

After you regroup expenses, you must change unlike dollars into current expenses. Maybe there have been several wage rate changes in the span of years you are analyzing. Finally, you must adjust for major changes contemplated to translate the effected expenses into future probable expenses. Prepare for the major changes both in expenses and in organization that will be in effect by the time budgets are put into operation.

Some of these revisions may be more easily made after the curves are drawn. Either way, the next step is to plot the several years of expenses against corresponding volumes.

CURVE PLOTTING

The first thing I do in this step is to select three or four vertical scales for expense dollars. Then I have the sheets with the volume scale already duplicated run off

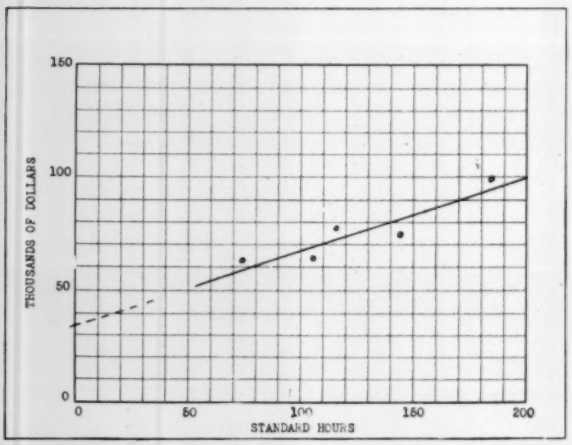

FIG. 2. (Draw trend line through your plots of historical expenses and extend to cross zero volume to read the constant cost.)

again to get quantities of dollar scales. Now you are ready to make a production job of curve plotting.

Each expense should be plotted separately. This can mean that any one manager may have his accountability represented by several budget curves. For instance, I always separate labor from materials. In Maintenance, you might have six curves.

Machines	Buildings
Maintenance Labor	Maintenance Labor
Maintenance Materials	Maintenance Materials
Contract work	Contract work

Like in timestudy, I believe in more rather than less detail. Remember, you may hardly get your budgets set up before other changes in organization will be made.

TREND LINES

To move on, the five years suggested earlier will enable you to plot five dollar amounts over five volume quantities. These will form a "scatter" diagram. Through these, I stretch a rubber band giving consideration to the factors behind the points.

Don't try to carry a guess to the fourth decimal place. These points represent series of errors. The first is lack of control. There could not have been much good control in the past because you are now setting up budgets to help overcome that weakness.

Second is lack of control related to changes in product mix. This will be discussed later.

Third is the lack of measurement. Usually, budgets are based on past performances. Generally, those for overhead labor are at day work pace. We might say that budget measures are comparable to those for "productive" labor back about 1800.

These errors are pointed out only to make sure we understand. Regardless, budgets give you a means for expense control that many firms do not yet have.

So you squint one eye and draw in trend lines. Practically, they represent the relations betwen expenses and volume for a going concern. Theoretically, you should dot the extensions of these lines from your lowest points until they cross the dollar scales of zero volume. See Fig. 2. I say dotted because the sheriff would have padlocked the front door long before you could get down to zero volume.

CONSTANT COST

These zero intercepts are the constant amounts in each expense. You can expect a constant in almost every curve. Take direct labor as one example most people think is purely variable. Suppose you have 100 people. Then suddenly, you are forced to reduce your work force to 50. If you are like most managers, you keep your better men in order to rebuild. Thus, your average wage cost per hour goes up. Hence, you have a constant cost even in direct labor.

The sum of all these constant costs is what causes the breakeven point on your profitgraph. I call this company constant the cost of the nucleus of the organization. Incidentally, contrary to the notion held by many, this constant is mostly people cost.

Anyhow, the constant amount for any expense is the first figure which is needed to set up budgets. I read off the amounts and record them beside each expense in a colunm headed Constant. This reading is a yearly amount. Therefore, to use with monthly budgets, you divide by 10.4 for 5-week and 13.0 for 4-week months.

VARIABLE EXPENSE

Now you can figure the variable costs. These are the slopes or rates of change of expense with volume. The slopes are relatively easy to compute. All you need are two sets of readings for each curve—two dollar amounts and their two corresponding volumes. You have these for zero volume—the constants. Suppose for the curve of Production Control this yearly constant is $35,000. Now assume this same curve reaches $100,000 expense at a volume of 200,000 standard hours. Then we can set down our readings as

	Volume		Expense
	200,000 S.H.		$100,000
Subtract	0	Constant	35,000
	200,000 S.H.		$ 65,000

Dividing the difference in standard hours into the difference in dollars, you get $.325 per standard hour. This is the slope. It is the variable cost per standard time unit and, of course, applies to yearly and monthly volumes. After you compute these for each curve, you should record the rates alongside their constants in a column labeled slope.

EXPENSE	CONSTANT	SLOPE
Timestudy	$20,000	$.200
Accounting	36,000	.620
Tool Room	29,000	.755
L. H. Power	25,000	.125
Depreciation	40,000	.000

Some curves like depreciation, taxes and insurance on equipment may not have slopes. Too, some curves may have negative slopes. For instance, I found one company's advertising expense, contrary to usual practice, to be high at low volume and low when business was good. In any event, your usual expense curves could be set down in equation form. Let's use Production Control on a 4-week basis as an example.

$$\text{Budget} = \$2692 + \$.325 \times \text{Standard Hours}$$

I never show a budget basis in this form. But I set it down that way here to bring the parts together so you can more readily see where we are at this stage.

BUDGET DOLLARS

Now let's apply our results. We can compute the budget for any period in advance when we know the forecast volume. And we can determine the budget after we know what the actual output was.

Take 11,056 as the actual standard hours of output for a 4-week month of June. Then, as one example, our budget for Production Control is 11,056 × $.325 plus $2692 making a total of $6285.

You can see by this example that to compute budgets for many expenses is easy. A good comptometer operator could figure those for a 100 expenses in about 25 minutes. That means you could compute them for planning expenses ahead of time and again afterwards to check actuals at very little cost.

The next step is to compare actuals with budgets. I do this on a sheet that has four columns for dollars. In the first column are the budgeted amounts for each expense. Next to these are the actuals. The third column is for gains—that is savings. The fourth shows losses.

VOLUME 11,056 STANDARD HOURS	BUDGET	JUNE 4 WEEKS ACTUAL	GAIN	LOSS
Timestudy	3,754	3,795		41
Accounting	9,626	9,510	116	
Tool Room	10,577	10,206	371	
L. H. Power	3,303	3,197	106	
Depreciation	3,077	2,906	171	

BUDGET DEFECTS

To digress for some explanation, you should recognize certain defects in budgets in order to improve upon their effectiveness. One may be obvious to you already. Budgets are dollar allotments. In no way do they specify what work should be done for the money budgeted. To illustrate, suppose you were to cut budgets 15 percent. Would the productivity improve that amount or would the work be piled in the corner?

You can see, then, that budgets can be improved and made more realistic by establishing work measures. In this process, you would discover a second defect. This is lack of count. We do not specify how often indirect work is to be done.

To illustrate, I like to tell the story about window washing. We set standards for the work and the men wanted to make more money. They worked diligently. They washed the windows six times in six months when they had not washed them previously but once in six years.

You see this in the offices. There we pile one report on top of another. I laugh to myself when I get a purchase order for a Discussion Leader's Manual or a film rental after I have been paid for the service.

Again, study of overhead operations can bring about important cost reductions. We should recognize that opportunities for improvement are at least as great as we have found in our long study of shop operations.

FUNCTIONS VERSUS PRODUCTS

The third defect you should be aware of is that of faulty measurement. It results from setting budgets, as we do, for functions of our organizations as distinguished

from products. For instance, I have talked about Production Control.

Carrying on, suppose for simplicity that you turn out only two products in your plant. Let's call them shirts and motors. Assume shirts are made up of 9 parts, motors of 90 parts. Right away, you can see there is less Production Control required for one shirt than one motor.

And Production Control work is also governed by orders. So quantity is a factor. Thus, if you make shirts in large lots and motors in small lots, the difference in Production Control effort is further exaggerated. Then we come to the factor of shop time. In comparison, one shirt takes very much less time to make than one motor. This fact tends to offset the other two.

Maybe in the aggregate, shirts take one fourth as much Production Control per shop standard time unit as motors. Such a supposition enables me to show the defect in arithmetic. Take the 11,056 standard hours and budget of $6285 for June. With our 1-4 ratio for Production Control, we could say that June Consisted of

	Hours	Prod. Control	Cost Rate
Shirts	5528	$1257	$.227
Motors	5528	$5028	.909
	11,056	$6285	

Now, let's assume that our shop output in July is exactly the same—11,056 standard hours. But our customers want more shirts and less motors. Suppose their orders raise shirt production to 8845 and reduce motor output to 2211 standard hours.

Then, making an assumption not wholly correct that the Production Control cost rates will be the same as for June, we can set budgets for July as

	Hours	Prod. Control	Cost Rate
Shirts	8845	$2008	$.227
Motors	2211	$2010	.909
	11,056	$4018	

Compare our new total of $4018 for the changed product mix with $6285 that would be allowed by the usual computation using an average budget variable rate. You see how far wrong budgets can be that neglect the inherent differences in overhead expenses caused by the different products in a business mix. Our overhead expenses are different for different products, different quantities, different customers and other differences. These will be recognized when you get around to seeking correct different overhead costs for your several products. More of this, if you are interested, in my book *How To Control Production Costs.*

COST CONTROL

Despite the weaknesses pointed out, budgets are valuable tools for cost control. As I put it, any control is better than "crisis hysteria." At the same time, you must keep in mind that budgets are just one more system. And systems are lifeless.

People spend money. People must control costs if budgets are to be worth their costs. Therefore, budgets are useful only to the extent that people are required to account for differences. Notice, I didn't say losses. Gains should be accounted for also. Maybe the work was put under the bench. That happened in one plant. There was a gain for three weeks in a row. Finally, someone discovered all the submerged repair work. You can guess what the budget showed the fourth week.

Management by exception calls for examining both gains and losses. That is especially true with budgets. One could say, "There should be very few losses," since most of the budgets are for people costs on an unmeasured basis. We should look for gains resulting both from better methods and better performances. We should not expect people in industry to spend all the budgets allow so as to get the same relative amounts next period as they do in our governments. Somebody has to make a profit in order to pay the taxes.

The point is that cost control comes about through management. This means people must be called to account for performances as measured by budgets.

And cost reductions come about through better management. That's why I stress the importance of analyzing the gains. If we can operate at a lower than budget cost this month, why not next month also? Said differently, if we always meet the budget, we have not made any improvements. We are not keeping up with competition. We are not increasing our standard of living. In America, there seem to be but two choices in managing business. These are, "Make profits or go broke."

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An Application of Game Theory in Incentives and Quality Control Problems

By LEON H. NISSIMOV
Industrial Consultant, Israel

TWO facts are established everywhere in industry, when norms and standards (usually based on time and motion study) are employed:[1]

1. Production increases, since the individual worker's output is quantitatively improved. (Accelerated production to attain higher earnings is a logical consequence of applying incentives).
2. If not efficiently controlled, quality is seriously deteriorated.

These two facts are expressed by the statement: "Production tops when quality drops."

In order to keep production at "an acceptable quality level," it seems, at first glance, necessary to inspect the standardized operations 100 percent. At times, such operations may be controlled 200 percent or more. But invariably, management arrives at the conclusion that 100 percent inspection is not completely efficient and as a matter of fact is always very costly.

The problem posed is very clear:—How to control most efficiently and economically hundreds (sometimes thousands) of standardized operations? The best and most economical solution often is by sampling. (Sampling, indeed, is the only alternative in cases where a destructive inspection is demanded. This is the case, for instance, where the tensile strength or chemical composition are to be checked.) The sampling technique of inspection is especially applicable for checking those operations and products which cannot be checked by automatic devices and the application of the Game Theory in such cases results in an extremely effective system.

The operator is usually in a position to keep the output within the accepted quality level and this is chiefly dependent upon both his skill and conscientiousness. But no matter how skilled and diligent the operator may be, a certain number of defective items will always be produced. Thus management must stipulate an "acceptable quality level," i.e., an allowable percentage of defective pieces. This allowable percentage is named "tolerance." When the percentage of defective pieces exceeds the tolerance, the entire lot may be rejected or each piece may then be inspected for acceptance. When an incentive system of remuneration is in force, it occurs frequently that an entire lot is rejected; then the rejected lot would be inspected piece by piece only if the cost of inspection is not prohibitive.

[1] In this paper, the standard time is accepted equal to 0.75 ×"Normal time."

It is always disruptive when quality is reduced. The responsibility for this is usually placed upon the operator. Part of the fault, however, is chargeable to the inefficiency of the inspection system as well. An economic and effective inspection system should:

a. Employ sampling methods of inspection.
b. Insure that neither the operator nor the company will lose or earn standard minutes in a long run, except in the cases pointed out in *f* and *g*.
c. Prevent any pay for defective work.
d. Decide on a sample size which being representative enough, will not impose an undue strain on the available inspection force.
e. Be practical and free from excessive clerical work.

The Game Theory when applied in practice will result in an inspection system which not only fulfills the above conditions, but in addition, it is easily applicable and has the definite advantage of keeping the output always within the accepted quality level. This is possible because the Game Theory takes into account the psychological behavior of the individuals operating in incentives. Thus:

f. In case an operator's defective output increases above the tolerance allowed, there is some risk of losing standard minutes. Practice confirms that few operators will deliberately reduce quality of their output, thereby impairing the chances of decent remuneration.
g. In case an operator improves quality and keeps the defective work below the allowable tolerance, there is increased chance of obtaining additional standard minutes. Practice proves that many operators will improve quality of their output, thus increasing the chances of supplementary remuneration.

Following is a brief description of a Game Theory situation in quality control, illustrated by an example, where the standard time for operation demanded to be inspected by sampling is 1 (one) minute ($s_t = 1$), the sample size is $n = 20$ percent, and the allowable defective percentage (tolerance) is 10 percent.

Figure 1 describes a Game situation between the operator A and the inspector B (in small shops B may be the foreman or other supervisor).

Let us examine the Game situation in Figure 1.

Player A—the operator is allowed two actions or two strategies: to operate satisfactorily or not to operate satisfactorily.

Player B—the inspector is allowed two strategies also: to inspect or not to inspect the job completed.

In Figure 1, X_1, X_2, X_3, X_4 are fictitious standard

Operator A	INSPECTOR B: $1-P_b=2/10$ Action "inspects"	INSPECTOR B: $P_b=8/10$ Action "does not inspect"
$P_a=1/10$ Action "does not operate satisfactorily"	$X_2=-3.675$	$X_1=0.918$
$1-P_a=9/10$ Action "operates satisfactorily"	$X_4=0.408$	$X_3=-0.102$

FIG. 1

minutes representing the pay-off of operator A. For any of his actions, A will get the appropriate pay-off which depends also upon the action chosen by B. For example:

1. A decides not to operate satisfactorily and B decides not to inspect the job completed; then A will get 0.918 standard minutes for each piece of bad quality.

2. A decides to operate satisfactorily and B decides to inspect; then A will get 0.408 standard minutes for the inspected piece found satisfactory.

3. A decides not to operate satisfactorily and B decides to inspect; then A will lose 3.675 standard minutes, for each piece of inadequate quality.

4. A decides to operate satisfactorily and B decides not to inspect; then A loses 0.102 standard minutes for each piece of good quality.

In fact, the application of the Game Theory is subjected to the condition that both players will choose their actions "at random," and that neither is able to guess what action the opponent player is likely to take. This condition is really fulfilled in practice for B, since table of random numbers may be utilized for the purpose of taking sample from current production. (Only sample drawn at random is believed to be representative).

Actions taken by A are believed to be randomized too. The mere fact that a certain percentage of defective pieces is allowable, confirms that it is highly probable that, during an 8 hours' work-day, an operator will produce some defective pieces at random.

In Figure 1. $P_a=1/10$ (or $1-P_a=9/10$) shows the probability that A may not do the job properly or the reverse. In our example, 1/10 is the tolerance limit adopted.

$P_b=8/10$ (or $1-P_b=2/10$) shows the probability with which B will choose not to inspect or to inspect and is the size of the sample established.

To clarify how the play is laid, let us imagine that between ten pieces produced one is not done properly.

B inspects at random only two pieces and, let us suppose he discovers a single defective piece, (this is highly improbable). Then the pay-off of A will be: $1\times0.408-1\times3.675-8\times0.102=-4.083$.

A loses -4.083 standard minutes.

In Game Theory's language, $P_a=1/10$ $(1-P_a=9/10)$, $P_b=8/10$ $(1-P_b=2/10)$ are called the best strategies for A and B respectively. Their meaning is clear enough. For instance, if B plays according to his best strategy, i.e., inspects at random 20 percent of the output, he insures that in a long run no player will benefit or lose standard minutes, no matter what percentage of defective production; and the opposite: if A plays according to his best strategy, i.e., holds poor production closed to the lower limit of the tolerance allowed $(P_a=1/10)$, he assures that in a long run nobody will benefit or lose standard minutes—no matter what the sample size.

DETERMINING THE VALUES OF X_1, X_2, X_3, X_4

In the beginning we will consider the method of determining the above values, and we will analyze the rules of the Game. Thereafter, several numerical examples will illustrate the simplicity of applying the Game Theory in practice, as well as its unlimited possibilities and great advantages.

Ordinarily, in Game Theory the payoff X_1, X_2, X_3, X_4 is predetermined, while the best strategies are not. But in our case, we are confronted with the opposite problem. The best strategies for both A and B are predetermined, these being the lower limit of the tolerance $P_a=1/10$ for A and the sample size of $1-P_b=2/10$ for B, while the four values of X_1, X_2, X_3, X_4 are unknown. Then, four independent equations are to be solved. When the best strategies are played for the purpose of insuring that neither A nor B will lose or benefit standard minutes, in a long run, the average payoff M to A should be zero (see fig. 1). Thus:

$$M = P_aP_bX_1 + P_a(1-P_b)X_2 + (1-P_a)P_bX_3 + (1-P_b)(1-P_a)X_4 = 0 \qquad \text{Eq. 1.}$$

or after algebraic manipulation

$$M = a(P_a-b)(P_b-c)+d=0 \qquad \text{Eq. 2.}$$

where

$$a = X_1 - X_2 - X_3 + X_4$$

$$b = \frac{X_4 - X_3}{a}$$

$$c = \frac{X_4 - X_2}{a}$$

$$d = \frac{X_1X_4 - X_2X_3}{a}$$

Then three of the four required equations are:

$$d = 0$$

$$c = P_b$$

$$b = P_a$$

The fourth equation is related to the Basic standard time $S_t=1$ and to the sample size 20%

$$X_1 + 0.2\,X_4 = 1$$

The meaning of this fourth equation is that in case the operator A turns out 100 percent quality work (that may happen) he should without any risk be entitled to get his

100 percent standard minutes. For example, in case the operator completes 100 units at 100 percent quality, he should receive what is due to him. In fact, it is possible to admit another expression for the fourth equation.[2]

$$100 \times 0.918 + 20 \times 0.408 = 100 \text{ standard minutes.}$$

Below—are resumed the four demanded equations:

$$X_1 X_4 - X_2 X_3 = 0 \qquad \text{(i)}$$

$$\frac{X_4 - X_2}{X_1 - X_2 - X_3 + X_4} - 8/10 = 0 \qquad \text{(ii)}$$

$$\frac{X_4 - X_3}{X_1 - X_2 - X_3 + X_4} - 1/10 = 0 \qquad \text{(iii)}$$

$$X_1 + 0.2_x X_4 - 1 = 0 \qquad \text{(iv)}$$

The Jacobian is different from zero and, therefore there are four independent equations:

$$\frac{D(f_1, f_2, f_3, f_4)}{D(X_1, X_2, X_3, X_4)} = \begin{vmatrix} \frac{\partial f_1}{\partial X_1} & \frac{\partial f_1}{\partial X_2} & \frac{\partial f_1}{\partial X_3} & \frac{\partial f_1}{\partial X_4} \\ \frac{\partial f_2}{\partial X_1} & \frac{\partial f_2}{\partial X_2} & \frac{\partial f_2}{\partial X_3} & \frac{\partial f_2}{\partial X_4} \\ \frac{\partial f_3}{\partial X_1} & \frac{\partial f_3}{\partial Y_2} & \frac{\partial f_3}{\partial X_3} & \frac{\partial f_3}{\partial X_4} \\ \frac{\partial f_4}{\partial X_1} & \frac{\partial f_4}{\partial X_2} & \frac{\partial f_4}{\partial X_3} & \frac{\partial f_4}{\partial X_4} \end{vmatrix} \neq 0$$

In practice, the four found values are necessary for computing the coefficient a

$$a = X_1 - X_2 - X_3 + X_4 = 5.103 \approx 5.1$$

and the basic expression 2 will receive the form

$$M = 5.1(Pa - 1/10)\ (Pb - 8/10) \qquad \text{Eq. 3.}$$

RULES OF THE GAME AND EXAMPLES

Analyzing the basic expression Eq. 3. we obtain the rules of the Game.

First rule: Whenever the inspector plays according to his best strategy, i.e., inspects at random 20 percent of the output, then $P_b = 8/10$, and in a long run, the expected average payoff M in standard minutes to A will be zero, no matter what the percentage of defective items P_a. In this case the computation of the standard minutes is very simple and does not differ at all from the ordinary way of calculation.

Numerical examples: 1. The total lot is 100 pieces. The sample size is 20 percent. The inspector finds one defective item among 20 inspected (M is zero because $P_b = 8/10$).

$$P = \frac{1}{20} \times 100 = 5\%$$

Operator should get

$$100 \times 1.0 - 5 \times 1.0 = 95 \text{ standard minutes}$$

2. The inspector finds 4 defective items among 20 inspected

$$P = \frac{4}{20} \times 100 = 20\%$$

Operator should get

$$100 \times 1.00 - 20 \times 1.0 = 80 \text{ standard minutes.}[3]$$

Second Rule: Whenever the inspector suspects that quality is deteriorated and the percentage of defective items much greater than the tolerance allowed, then he is in position to abandon his present strategy and increase the size of the sample over 20 percent ($P_b < 8/10$).

Analyzing the basic expression Eq. 3. we realize that any increase of the sample size will jeopardize the payoff to A where the latter is actually turning out inadequate production over the tolerance allowed ($P_a > 1/10$), the expected average payoff M becoming negative ($M < 0$). The opposite is likewise true that if the operator is moving within the tolerance ($P_a < 1/10$), his chances for an increased payoff are likely to materialize; M becoming positive ($M > 0$).

The computation of the standard minutes is the same as the previous, with some correction of M that has to be introduced.

We have named this correction "quality level factor."

Table 1 indicates the scale of the correction M (Principally negative—operator loses standard minutes!) when A increases the percentage of defective units from 1/10 to 2/10 and the inspector increases the sample size from 20 percent to 30 percent, the total lot produced being $N = 50$.

Table 1 for $P_b = 7/10$, $P = 2/10$, $N = 50$.

From Table 1 we conclude as follows:

1. The loss most probable to occur to A is $M = -5.1\%$ with probability of 0.224 (probabilities are computed approximately by the Poisson distribution).
2. The upper limit is positive and $M = 5.1\%$, but the chance of not drawing any defective piece is very small (probability 0.05).
3. The lower limit is negative and $M = -28.9$. This is a considerable loss for A, but the probability of this ever occurring is very small too (probability < 0.001).
4. In general, there are 0.8 chances—against 0.2 that A loses standard minutes.

Example: If three defective units will be discovered ($P_a = 20\%$), the operator should get:

[2] If we admit the fourth equation to be $X_1 = 1$, it will change slightly the absolute value of a. Then $X_2 = -4$, $X_3 = 1/9$, $X_4 = 4/9$ and $a = \frac{55}{9}$. For each basic standard time with value V, (that is, $S_t = V$), then $a = \frac{55}{9} V$.

[3] In the course of his routine work, the inspector will find sometimes higher and sometimes lower percentages instead of the true defective percentage, but over a period of time, they will be equalized and neither the operator nor the company will earn or lose standard minutes.

TABLE 1

Percent of defective items discovered	Number of defective items discovered	$M=\frac{5.1}{10}\left(P_a-\frac{1}{10}\right)$	Probability for discovering defective items
P_a %	n	%	$P_n=\frac{m^n e^{-m}}{n!}$
0.0	0	5.1	0.050
6.7	1	1.7	0.149
13.3	2	− 1.7	0.224
20.0	3	− 5.1	0.224
26.7	4	− 8.5	0.168
33.3	5	−11.9	0.101
40.0	6	−15.3	0.050
46.7	7	−18.7	0.022
53.3	8	−22.1	0.008
60.0	9	−25.5	0.003
66.7	10	−28.9	0.001

$$50 \times 1.0 - 0.2 \times 50 \times 1.0 = 40.00$$
$$M = -0.051 \times 50 = -2.55$$
$$37.45 \text{ standard minutes}$$

The operator loses 2.55 standard minutes.

Table 2 indicates the situation where with added effort A improves quality, decreasing the percentage of defective units from 1/10 to 5/100. Sample size—40%.

TABLE 2

$N=100$, $P_b=6/10$, $P=5/100$

Percent of defective items discovered	Number of defective items discovered	$M=-\frac{10.2}{10}\left(P_a-\frac{1}{10}\right)$	Probability for discovering defective items
P_a %	n	%	$P_n=\frac{m^n e^{-m}}{n!}$
0	0	10.2	0.135
2.5	1	7.65	0.270
5.0	2	5.10	0.270
7.5	3	2.55	0.160
10.0	4	0.00	0.090
12.5	5	−2.55	0.036

Example: If one defective unit will be discovered, $P_a=2.5\%$, the operator should get:

$$100\times1.0-0.025\times100\times1.0=97.50$$
$$M=0.0765\times100=7.65$$
$$105.15 \text{ standard minutes}$$
$$\approx 105.2$$

In this case the operator will be remunerated with 10.2 (ten point two) standard minutes.

Note: we can check this result with the scales of figure 1. A will receive:

$39\times0.048=$	15.912	when A operates satisfactorily and B inspects
$4\times0.918=$	3.672	when A does not operate satisfactorily and B does not inspect
$-56\times0.102=-$	5.712	when A operates satisfactorily and B does not inspect
$-1\times3.675=-$	3.675	when A does not operate satisfactorily and B inspects.
in total	$10.197\approx10.2$	standard minutes at remuneration

RECAPITULATION

In order to apply the Game Theory in quality control where an incentive system is available, the following has to be accomplished:

1. Standardize the operation through a time and motion study.
2. Determine the inspection method. If sampling is used, the size of the sample has to be defined in view of the available inspection force. This size will represent the "best" strategy.
3. Determine the defective tolerance. This tolerance moves within different limits (and is always subject to discussions) but in industry rarely does it exceed 10 percent.
4. Calculate the values of X_1, X_2, X_3, X_4 and afterwards the coefficient a. This will make it possible to obtain the expression for the quality level factor M.
5. Before introducing the method, both operator and union representatives have to be briefed and the basic principle of the theory explained to them.
6. Instruct inspectors. Inspectors should periodically increase the sample size over the best strategy (but never decrease it!) in order to maintain the interest of operators in turning out high quality production. The sample size is increased in every case when there is indication of quality deterioration.
7. Explain to the clerical staff how the computation of the standard minutes is to be performed, and prepare tables for M to facilitate the calculation.

REFERENCE

(1) Von Neumann, John, and Morgenstern, Oscar, *Theory of Games and Economic Behaviour*, Princeton University Press, 1944.

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Travel Charting with Realistic Criteria

by **ROBERT W. LLEWELLYN**

Associate Professor of Industrial Engineering, North Carolina State College

MOST Industrial Engineers were first introduced to travel charting by Wayland P. Smith's article (3). Some aspects of his method were reviewed by Lundy (2). An alternate method of determining machine placement in plants having a non-uniform product flow was presented by Buffa (1). This article will deal with a type of travel charting which extends the work of Smith and Lundy and incorporates some of the concepts presented by Buffa.

Following Smith's lead, the method will be presented by means of an example. Consider the eight products listed in Table 1. The sequences of operations, parts per month and unit load sizes were assumed. The total number of loads per product per month were then calculated to complete the table. Table 2 is a statement of the number of square feet of space needed for each department. While these data were assumed here, they can always be determined from production data. Figure 1 shows a trial layout of the departments concerned. In many instances, the first trial layout would be the layout in use when the analysis was started.

Having this layout drawn to scale, it was then possible to construct the Distance Chart of Table 3. In determining the distance between departments, the following assumptions were made:

1. In order to go from any department to any other department, a truck must first go out to the aisle, then along the aisle to a point opposite the next department and then into that department.
2. It was assumed that the average point moved to or away from in each department was the center of that department.
3. Moves from the raw material area were assumed to start, on the average, from points X or Y (Figure 1) rather than from the center of the area. The same reasoning was applied to the finished goods area.

TABLE 1

Products and Sequences

Product No.	Sequence	Parts/month	Parts/load	Loads/month
1	RM-A-C-F-D-B-FG	4000	200	20
2	RM-C-D-C-F-FG	10000	500	20
3	RM-A-F-B-E-D-FG	6000	200	30
4	RM-B-F-D-FG	2000	500	4
5	RM-C-F-E-D-FG	8000	400	20
6	RM-E-D-F-C-D-FG	3000	600	5
7	RM-C-B-F-D-FG	4000	800	5
8	RM-A-F-E-D-FG	12000	1000	12
				116

TABLE 2

Department Areas

RM (Raw Materials)	1600 Square feet
A	700
B	700
C	1050
D	1125
E	1725
F	1575
FG (Finished Goods)	1600

The next step was to construct the Move Chart (Table 4), which was done in the same manner in which Smith constructed his travel chart of unit moves. It shows the total number of unitized loads for all products from each department to each other department. Movements above the diagonal line indicate backward travel as they did in Smith's chart.

The Travel Chart (Table 5) was then constructed by multiplying each entry in the Distance Chart (Table 3) by the corresponding entry in the Move Chart (Table 4). The result was a table which shows the total movements of the products from each department to each other department in move-feet per month. By adding columns and rows in Table 5, the total travel from each department and the total travel to each department was obtained. A partial check on the calculations is that the row totals should equal the column totals. This grand total is the number of move-feet per month necessary to accomplish all moves.

In order to establish a criterion for determining the efficiency of the system, the following reasoning was used:

1. To get out of the department, a load must be moved 22 feet

TABLE 3

Distance Chart of First Layout

TO \ FROM	RM	A	B	C	D	E	F	FG
RM		64	64	89	92	129	132	164
A	64		44	69	72	109	112	144
B	64	44		69	72	109	112	144
C	89	69	69		47	84	87	119
D	92	72	72	47		81	84	116
E	129	109	109	84	81		47	79
F	132	112	112	87	84	47		76
FG	164	144	144	119	116	79	76	

TABLE 4

Move Chart of First Layout

TO \ FROM	RM	A	B	C	D	E	F	FG	Totals
RM									
A	62								62
B	4			5	20		30		59
C	45	20			20		5		90
D				25		67	29		121
E	5		30				32		67
F		42	9	60	5				116
FG			20		76		20		116
Totals	116	62	59	90	121	67	116		

TABLE 5

Travel Chart of First Layout

TO \ FROM	RM	A	B	C	D	E	F	FG	Totals
RM									
A	3968								3968
B	256			345	1440		3360		5401
C	4005	1380			940		435		6760
D				1175		5427	2436		9038
E	645		3270				1504		5419
F		4704	1008	5220	420				11352
FG			2880		8816		1520		13216
Totals	8874	6084	7158	6740	11616	5427	9255		55154

to get to the center of the aisle. To get into another department, the load must be moved an equal distance. Thus 44 feet of "internal" travel was required per move.

2. Table 6 was used to determine the average amount of aisle movement per move. First the number of moves per product (between departments) was multiplied by the number of loads per month of that product. Then the weighted average number of moves per product was obtained by adding the results of the above multiplications and dividing by the total number of loads per month from Table 1. The result of this calculation was that the average number of moves per product is 5.45. Since each product starts in the raw material area and ends in the finished goods area, it must move 120 feet in the "forward" direction. Therefore, the average travel along the aisle per move would be 120/5.45 or 22 feet if no backtracking occurred.
3. Adding the "internal" travel to the aisle travel gives a total of 66 feet of travel for the average move for the condition of no backward travel.

TABLE 6

Calculation of Average Aisle Distance per Move

Product No.	No. of Moves	Loads/month	Moves/product/month
1	6	20	120
2	5	20	100
3	6	30	180
4	4	4	16
5	5	20	100
6	6	5	30
7	5	5	25
8	5	12	60
		116	631

Weighted average moves/product = 631/116 = 5.45 moves per product. Average distance per move = 120/5.45 = 22 feet.

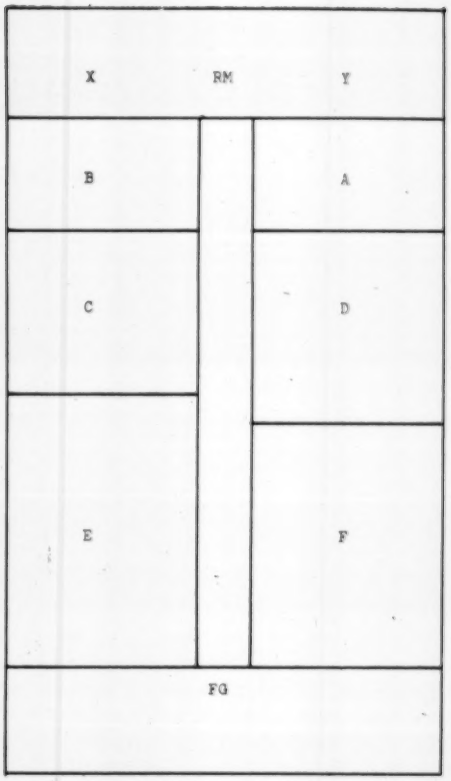

FIG. 1. Original Layout (Scale 1/16" = 1')

The last step in the analysis of the first trial layout, then, is shown in Table 7. The *Optimum* travel *from* each

TABLE 7

Calculation of Optimum Travel and of Efficiencies for First Layout

Dept.	Distance	Moves	Optimum	Actual	Efficiency
MOVES FROM					
RM	66	116	7656	8874	86.3%
A	66	62	4092	6084	67.3
B	66	59	3894	7158	54.4
C	66	90	5940	6740	88.1
D	66	121	7986	11616	68.8
E	66	67	4422	5427	81.5
F	66	116	7656	9255	82.7
FG			41646	55154	75.5
MOVES TO					
A	66	62	4092	3968	103.1%
B	66	59	3894	5401	72.1
C	66	90	5940	6760	87.9
D	66	121	7986	9038	88.4
E	66	67	4422	5419	81.6
F	66	116	7656	11352	67.4
FG	66	116	7656	13216	57.9
			41646	55154	75.5

department was obtained by multiplying the sums of the columns of the Move Chart (Table 4) by 66 feet. The *Actual* travel *from* each department is the total of the corresponding column of the Travel Chart (Table 5). The *Optimum* and *Actual* travel *to* each department was obtained in the same way by working with the row totals from the same charts. The ratio of optimum to actual is the efficiency of each combination. The result is the efficiency of each department in relation to the work leaving and entering the department. The overall efficiency for the entire layout is also obtained.

In the problem, departments A, B and D were poorly located in relation to the destinations of materials leaving the departments, as indicated by the efficiency figures. Departments B and F and the finished goods area were poorly located in relation to the departments immediately preceding them in the processes. A consideration of these facts together with a study of moves charted above the diagonal line on the Travel Chart lead to the conclusion that department B should be further down the aisle and that department D should be located adjacent to the finished goods area. This rearrangement of departments is shown in Figure 2.

This layout was then evaluated in steps as follows:

1. A new Distance Chart was made (Table 8).
2. A new Move Chart was made (Table 9). Note that this involves merely a relisting of departments as compared to Table 4. This chart was made to simplify the next step.
3. A new Travel Chart was made (Table 10).
4. Efficiencies of the layout were computed (Table 11). Note that the optimum travels are the same as in the first layout (Table 7).

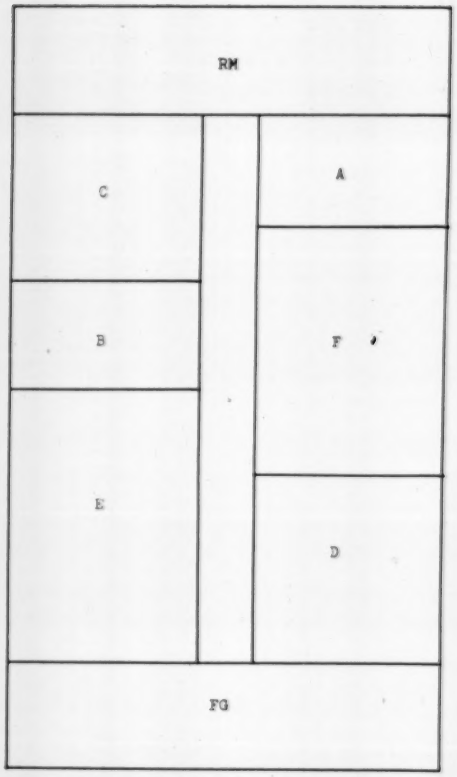

FIG. 2. Revised Layout (Scale 1/16" = 1')

The efficiency of the overall system has been raised from 75.5% to 88.6%. More significant, the total travel has been reduced from 55,154 move-feet to 46,984 move-feet, a saving of 8,170 move-feet per month. It might be possible to further improve the layout, but the example has now served its purpose.

TABLE 8

Distance Chart of Second Layout

		FROM							
		RM	A	C	B	F	E	D	FG
TO	RM		64	69	94	97	129	137	164
	A	64		49	74	77	109	117	144
	C	69	49		69	72	104	112	139
	B	94	74	69		47	79	87	114
	F	97	77	72	47		76	84	111
	E	129	109	104	79	76		52	79
	D	137	117	112	87	84	52		71
	FG	164	144	139	114	111	79	71	

TABLE 9

Move Chart of Second Layout

		FROM								
		RM	A	C	B	F	E	D	FG	TOTALS
TO	RM									
	A	62								62
	C	45	20			5		20		90
	B	4		5		50		20		59
	F		42	60	9			5		116
	E	5			30	32				67
	D			25		29	67			121
	FG				20	20		76		116
Totals		116	62	90	59	116	67	121		

TABLE 10

Travel Chart of Second Layout

		FROM								
		RM	A	C	B	F	E	D	FG	Totals
TO	RM									
	A	3968								3968
	C	3105	980			360		2240		6685
	B	376		345		1410		1740		3871
	F		3234	4320	423			420		8397
	E	645			2370	2432				5447
	D			2800		2436	3484			8720
	FG				2280	2220		5396		9896
Totals		8094	4214	7465	5073	8858	3484	9796		46984

TABLE 11

Calculation of Optimum Travel and of Efficiencies of Second Layout

Department	No. of Moves	Optimum Move-Feet	Actual Move-Feet	Efficiency
MOVES FROM				
RM	116	7656	8094	94.6%
A	62	4092	4214	97.1
B	59	3894	5073	76.8
C	90	5940	7465	79.6
D	121	7986	9796	81.5
E	67	4422	3484	126.9
F	116	7656	8858	86.4
		41646	46984	88.6
MOVES TO				
A	62	4092	3968	103.1%
B	59	3894	3871	100.6
C	90	5940	6685	88.9
D	121	7986	8720	91.6
E	67	4422	5447	81.2
F	116	7656	8397	91.2
FG	116	7656	9896	77.4
		41646	46984	88.6

Some comments are needed on the assumptions and criteria used.

1. It was assumed that all movements must be made via the aisle rather than go directly across department lines. That is not essential to the system and if more direct movements are possible, they should be so handled.
2. Backward travel was given the same weight as forward travel. The penalty for backward travel is automatically included in the method. If a product goes backwards at some point in the process, it must traverse a given aisle length three times (forwards, backwards, then forwards again) instead of once. Also, it costs no more to move the material backwards than it does to move it forwards. Elimination of the artificial penalty for backwards travel allows the problem to be worked in terms of actual travel distances and avoids a "loading" of the method that could easily lead to layouts of less than optimum efficiency.
3. The method of computing the optimum distance traveled in an average move was rather arbitrary. Its use leads to efficiencies of over 100% for some departments. This happened when most of the moves from or to a department were of distances up or down the aisle shorter than the average computed in Table 6. A substitute criterion could be the shortest move possible in a forward direction. This, however, could still lead to efficiencies in excess of 100% if shorter backward moves were possible. Still another criterion could be the shortest move possible in either direction; this might lead to evaluating forward moves in terms of backward moves which are shorter but inefficient. The prime advantage of the criterion used is that the optimum move distance is the same for all departments and remains the same in later trial layouts unless the raw materials and finished goods areas are moved. This is not true of the alternate criteria suggested. The criterion is used only in determining the additional trial layouts, in any event. The real test of a given layout is the total number of move-feet required to complete all processes as compared with the move-feet required with alternate layouts.
4. This problem was worked with unit load data rather than weight. Because of the nature of the problem, conveyor systems can not be considered. The material must be moved with fork trucks, platform trucks, hands trucks or similar equipment, all of which demand unitizing the load to the largest practical size for maximum efficiency. Once that is done, the weight differences of loads of the various products is a small factor, while the number of moves and their distances are very important.

The advantages of this type of charting appear to be:

1. The distance figures are realistic. They reflect the actual areas occupied by the departments and include the travel within the departments.
2. Efficiencies are obtained for each department in addition to the overall efficiency. These are of benefit in proceeding to the best layout in the minimum number of steps.
3. The calculations are in a form which the line personnel can appreciate and which do not contain any assumptions contrary to their concepts of the situation.
4. The method can be extended to any number of products, any number of departments and any shape of building. Some ingenuity may be needed in determining the criterion on which to base the department efficiencies when working with some odd shaped buildings, but a working criterion should always be possible.
5. The method is not limited to working with any given list of products. When the product mix is constantly changing, a sampling procedure can be used in the shop to estimate the number of moves per some unit of time between departments. These would then be posted directly to the Move Chart. Then, working with a Distance Chart of the existing plant, the first Travel Chart may be prepared and the analysis begun.

REFERENCES

(1) Buffa, Elwood S., "Sequence Analysis for Functional Layout," *Journal of Industrial Engineering*, March-April, 1955.

(2) Lundy, James L., "A Reply to Wayland P. Smith's Article," *Journal of Industrial Engineering*, May-June, 1955.

(3) Smith, Wayland P., "Travel Charting," *Journal of Industrial Engineering*, January, 1955.

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THURSDAY—June 12, 1958

8:00-9:00 A.M. **Registration & Exhibits**

Keynote Address: 9:00 A.M.
Gateway to Productivity
Gen. Ben I. Funk, Deputy Director Ballistic Missiles, Air Materiel Command

General Session I 10:30 A.M.
The Industrial Engineers' Concept of Productivity

I-A Productivity in Manufacturing
Electronics
R. B. Parkhurst, Vice-President, Manufacturing, Hughes Aircraft
Aircraft
T. L. McCarthy, Director of Masters Programs and Analysis, Northrop Aircraft, Inc.
Light Manufacturing
W. H. Trumbull, Vice-President, Paper Mate Manufacturing Company
Chairman: Harry J. Kraig, Ernst & Ernst, Sierra Room

I-B Productivity in Processing
Petroleum
R. M. Brown, General Superintendent of Operations, Union Oil Company
Steel
T. L. Carroll, Chief Industrial Engineer, Columbia-Geneva Division, United States Steel
Food
A. L. Buffington, Production Manager, Diamond Walnut Growers, Inc.
Chairman: Walter R. Herbst, Consolidated Western Steel Division, United States Steel, Wilshire Room

I-C Productivity in Service Industries
Insurance
Wesley S. Bagby, Comptroller, Pacific Mutual Life Insurance Company
Transportation
John M. Gilbreth, Manager of Operations Research, Grace Lines, Inc.
Retail
Alvin M. Ferst, Jr., Supt. Planning & Plant Management, Rich's, Inc.
Chairman: Donald L. Mihelich, Bobrick Manufacturing Corporation, Garden Room

LUNCHEON 12:00 NOON
Human Engineering
Charles Luckman, Pereira & Luckman
Chairman: Arthur L. Chilman, Columbia-Geneva Division, U. S. Steel, Pacific Ballroom

General Session II 2:00 P.M.
Productivity Realized Through Industrial Engineering Analysis

II-A Engineering Applications
Product Design
Melvin H. Best, President, Melvin Best Associates
New Product Development—Pre-production Planning
Arthur J. Casebeer, Planning Director & Production Manager, Cannon Electric Company
Facilities Utilization & Planning
Dr. William T. Morris, Department of Industrial Engineering, Ohio State University
Chairman: N. Perkowski, Assistant Professor, University of Southern California, Sierra Room

II-B Management Applications
Factors in The Economic Analysis of Automatic Equipment
Raymond R. Mayer, Associate Professor, School of Business, University of Chicago
The Techniques of Profit Control
Charles A. Bogenrief, Department Head, Industrial & Plant Engineering, Robertshaw Fulton Controls Co.
Organization Analysis—A New Frontier of Industrial Engineering
Charles F. Rowbotham, Long Range Planning Coordinator, Rocketdyne, Div. North American Aviation, Inc.
Chairman: Howard P. Emerson, Professor, University of Tennessee, Wilshire Room

Special Session I 2:00 P.M.
Productivity Demonstrated—A Case Study of Industrial Engineering in Action
D. D. Henion, West Coast District Manager, Management Services Division
J. D. McFadden, Management Consultant, Ernst and Ernst
Chairman: Peter P. Pruce, Ernst and Ernst, Garden Room

Technical Session I 2:00 P.M.
Linear Programming—Planning for Optimum Productivity
Dr. William Karush, Systems Development Corporation
Chairman: Ira K. Hearn, Kennecott Copper Corporation, St. Louis Room

BANQUET 7:00 P.M.
Some Economic Aspects of the Cold War
Dr. Neil H. Jacoby, Dean, Graduate School

of Business, University of California, Los Angeles

Chairman: Howard Dickason, Anderson-Nichols & Co., Pacific Ballroom

FRIDAY—June 13, 1958

General Session III, 9:00 A.M. — **Advanced Industrial Engineering Methodology**

III-A Systems Analysis

Monte Carlo Methods

Dr. G. W. Brown, Director Western Data Processing Center, UCLA

Simulation, Game Theory and the Theory of the Firm

Dr. Martin Shubik, Consultant, General Electric Co.

Some Practical Simulations of Operations

Dr. John B. Lathrop, Manager Operations Research, Lockheed Aircraft Corp.

Chairman: Arnold A. Cowan, Bobrick Mfg. Corp., Sierra Room

III-B Manufacturing Analysis

Automatic Production Recording

E. Howard Gee, Manager, Western Region, Time Equipment Division, IBM

Automatic Production Control

Tom C. Fisher, Special Representative, Western Region, Data Processing Division, IBM

Computerized Production Control

J. T. Clark, Production Manager, Poughkeepsie Plant, IBM

Chairman: Lee S. Sharp, Consolidated Western Steel Division, U. S. Steel, Wilshire Room

Technical Panels, 9:00 A.M. — **I—Electronic Data Processing—The Fourth Dimension of Productivity**

Experience in Multiplying Defense Capabilities Through Data Processing

Charles A. Phillips, Director, Data Systems Research Staff, Office of Asst. Secretary of Defense

Experience in Utilizing Computers in the Management Control Loop

John Hawk, Director, Applied Science, The Service Bureau Corp.

The Impact of EDPM on Jobs, Procedures and People

J. D. Elliott, Supt. of Revenue Accounting, Detroit Edison Company

Chairman: Maurice D. Pratt, IBM, Garden-West Room

II—Increased Profits in Small Plants

Production, Purchasing and Inventory Controls

N. A. Lamberri, Vice-President and General Manager, Ryder-Elliott, Inc.

Working Capital, Replacement Capital & Expansion Capital for Small Plants

Leonard Weil, Vice-President & Manager, Installment Loan Dept., Union Bank & Trust Company

Small Plant Sales & Contracts

Donald L. Driscoll, Vice-President, Contracts & Sales, Cal-Tronics Corporation

Industrial Relations & Incentives in Small Plants

Martin S. Meyers, General Manager, Utility Cabinet Co.

Chairman: Homer H. Grant, Head, Industrial Engineering, University of Southern California, New York Room

III—Psychology and Productivity

Drive Them—or Lead Them

Dr. Harry L. Coderre, Partner, Rohrer, Hibler & Replogle

Dr. Milton Gordon, Associate Director, Management Development Center, California Institute of Technology

Mark Lundin, Industrial Relations Manager, Western Division, The Dow Chemical Co., Pittsburg, California

Chairman: Edwards R. Fish, Jr., Northwestern Glass Company, Washington, Garden Room

LUNCHEON, 12:00 NOON — **Motivating Engineers**

Dr. Robert S. Bell, President, Packard-Bell Electronics Corp.

Chairman: C. Wilson Whitston, President, Markets Unlimited; President, Los Angeles Chapter AIIE, Ballroom

Special Session II, 2:00 P.M. — **Management of New Products**

Ralph W. Jones, Booz, Allen and Hamilton, Management Consltants

Chairman: John E. Jardine III, Maghead Laboratories, Sierra Room

Technical Panel IV, 2:00 P.M. — **Job Simplification vs Job Enlargement**

Dr. R. N. Lehrer, Chairman, Industrial Engineering Dept., Northwwestern University

Dr. Neil D. Warren, Prof. & Head Dept. of Psychology, University of Southern California

Chairman: Joseph D. Carrabino, Associate Professor, UCLA, Wilshire Room

Technical Session II, 2:00 P.M. — **Productivity Without Compromise**

Industrial Engineering versus The Burden of the Past

Frank H. Squires, Director of Quality Control, Topp Manufacturing Company

Productivity Through Attention to Quality

Prof. W. Grant Ireson, Executive Head, Department of Industrial Engineering, Stanford University

Chairman: Dale L. Lobsinger, United Air Lines, Garden Room

General Session IV, 3:30 P.M. — **Human Implications of Productivity—The Social Responsibilities of Industrial Engineering**

Dr. Adam Abruzzi, Professor of Industrial Engineering, Stevens Institute of Technology

Chairman: Donald L. Johnson, Convair Division, Consolidated Electrodynamics Corp., Pacific Ballroom

SATURDAY—June 14, 1958

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8:00 Delegate Registration
9:00 Convention Session
12:00 Luncheon: Keynote Address of the President-Elect
2:00 Afternoon Convention Session

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Reader Comments

THE INDUSTRIAL ENGINEER IN GOVERNMENT, by Frank T. Geyer, *Journal of Industrial Engineering*, November-December, 1957.

My compliments on your article by Mr. Frank Geyer, "The Industrial Engineer in Government," in the November–December, 1957, issue. Particularly, I refer to the sections on the Military Industrial Engineer and the Military Industrial Engineer as a Supervisor.

My keen interest and appraisal of these sections is a natural turn of events because of my background. I am a graduate of the United States Military Academy (West Point). Having resigned from the Regular Army several years ago, I am now in Industrial Engineering in non-government work. Considering my education at West Point, furthered by some graduate work, I believe that I can speak with some degree of experience as the "generalist" you speak of, and as the "specialist" you refer to.

My field and garrison experience in the military has been primarily as an Infantry Company Commander, and on staff. I wish to point out that there lies a closeness in these areas for the Industrial Engineering "thinking." These are easily recognizable in the scope of the commanders' and staff officers' duties and responsibilities: the administrative functions, supply responsibilities, manpower management (personnel), education and training. Even the awareness to the comparison of a layout of "foxholes and fortifications" to a plant layout should not be overlooked. A commander finds problems of a logistical nature, communications, proper use of ancillary personnel and decisions beyond the pure military tactics and strategy. My further military education at basic and advanced officers schools covered aspects directly associated with Industrial Engineering. In fact, certain forms and methods used may be found identical with those in Industrial Engineering Handbooks.

Thus, the place of the Industrial Engineer, I believe, extends beyond those areas listed in the article. *In all connections with the military services, a knowledge, understanding, and proper application of the military aspects commensurate with one's position is an absolute necessity.* The two go hand-in-glove. Perhaps your classification of an Industrial Engineer in the capacity of "Military Administrator" is a closer acknowledgment of what I bring out. For indeed, there is a likeness of Industrial Engineering "thinking" and the mental processes a military leader, from squad leader up to senior commander, must go through. *Melvin A. Young, Creve Coeur, Missouri.*

THE HIGHER OBJECTIVES OF INDUSTRIAL ENGINEERING, by M. A. Payne, *Journal of Industrial Engineering*, March-April, 1957.

I have recently re-read Mr. Payne's, "The Higher Objectives of Industrial Engineering" after several months. In this article Mr. Payne has, so to speak, forged out an ideal for Industrial Engineering. This is something that Industrial Engineering has needed since its inception, for it has too long been chiefly concerned with its details, namely, its techniques such as motion and time study, production control, etc. As valuable as these techniques are, the fact remains they are easily acquired and have little appeal to the idealism of people. What Industrial Engineering has needed and what Payne has supplied is a grand ideal to work toward—an objective that is not only sound but emotionally appealing. I salute him for his approach.

Organization, which is in my view the Industrial Engineer's real area of operation, is man's greatest invention. Essentially organization is a labor saving invention. But it is even more than this, for human satisfactions are created by organizations, thus aiding people to realize their aspirations. This concept, it seems to me, needs to be crystalized in the objective of Industrial Engineering for it to have wide appeal.

In my mind the Industrial Engineer is essentially a manager who employs materials, machines and physical and mental efforts of people in production of utilities for the satisfaction of people. In my opinion, the function of a manager is to direct persons in such a manner that he and those he directs more nearly realize their aspirations than they otherwise could. In other words, the function of a manager, and so, the function of Industrial Engineering, is the realization of human aspirations through organized effort.

Tead, in his Art of Leadership, published by McGraw-Hill many years ago defines leadership as the "activity of influencing people to cooperate towards ends that they come to desire." This idea is essentially embodied in Mr. Payne's statement which reads, "The objective of Industrial Engineering is to help mankind attain perfection in the application of its abilities and talents." However, the idea of perfection in his statement appears to me to miss the point slightly. In my way of thinking, perfection in the application of talents, is not an end but a means. This leads me to suggest, "The basic objective of Industrial Engineering is to help mankind to apply its abilities and talents with optimum fruitfulness (with respect to both objectives and means)." This objective is similar to that advanced in 1908 by a Professor Stott in a definition that reads, "ENGINEERING—The art of organizing and directing men and controlling the forces and materials of nature for the benefit of the human race."

Our local Oklahoma Society of Professional Engineers recently asked a leading lawyer to talk on the subject of "legal professionalism." He stated that the preparation for this talk had done him a great deal of good because of the occasion of his reading the lawyer's oath and code of ethics. This was the first time he had read it since being admitted to practice—some 14 years before. He had forgotten the ideals he once professed—and still believed in. Likewise, it would do us well to read Payne's message every once in a while.

Mr. Payne is doing Industrial Engineering and AIIE a great service in seeking to crystallize an ideal toward which we can work. We should all join him in his effort.—*H. G. Thuesen, Professor, School of Industrial Engineering and Management, Oklahoma State University.*

MEASURES OF THE EFFICIENCY OF ACCEPTANCE SAMPLING PLANS, by Tee H. Hiett, Jr., and Don S. Holmes, *Journal of Industrial Engineering*, July-August, 1957.

Equations 5 and 6 should be as follows:

$$E_p = \frac{c+1}{nAQL} - \frac{1}{nAQL} \sum_{x=0}^{c} \sum_{i=0}^{x} \frac{(nAQL)^i e^{-nAQL}}{i!}$$

$$E_c = 1 - \frac{1}{n(1-AQL)} \sum_{x=0}^{c} \sum_{i=0}^{x} \frac{(nAQL)^i e^{-nAQL}}{i!}$$

The charts presented in the article are correct as they were developed from the above equations.—*Tee H. Hiett, Jr., and Don S. Holmes.*

Recent Readables

AUTOMATION

"Automate with 'Off-The-Shelf' Equipment," by Chester Linsky, FLOW, *April, 1957.*

Too many manufacturers stay clear of automation because they are afraid it will inevitably involve expensive, highly specialized machines which must be amortized over short periods, says the author. Pointing out that a firm does not have to make complete automation its immediate goal, he describes some low-cost, standard equipment available and gives concrete examples of how it can be incorporated with a plant's present facilities to profitably increase mechanization of operations.

"Evaluating Production Equipment for Automation," by D. A. Cargill, P. H. Richardson, Val Wallace Baran, Robert Sattler, and J. H. McRainey, AUTOMATION, *May, 1957.*

This special 27-page roundup of basic automation equipment and techniques should be a useful guide in helping a company select the type of equipment most suited to its specific needs and purposes. Included are sections on: 1. using standard equipment, 2. applying "building block" techniques, 3. using transfer machines, 4. developing special-purpose equipment, and 5. using tape- and card-controlled machines for short runs and job lots.

"Mechanical-Assembly Equipment," by G. R. Fitzgerald, MECHANICAL ENGINEERING, *April, 1957.*

Companies should be on their guard against mechanizing their assembly processes on the assumption that "because it is automatic it is good," says the author, pointing out that automatic assembly is not always the best solution from a cost standpoint. He recommends a detailed study of existing facilities to determine the exact degree of assembly automation necessary to produce maximum efficiency at reasonable cost.

"The Astonishing Computers," by William B. Harris, FORTUNE, *June, 1957.*

Since 1954, when the first sale of a large-scale electronic computer to process business-office data was made, more than 1,200 computers have gone into commercial use. But despite this dazzling boom, says the author, computer manufacturers face difficult problems: It is costly to educate new owners in how to use the complex machines, production is painfully slow, and, since 80 percent of computers are rented rather than sold, manufacturers' financial requirements are enormous.

"The Impact of Automation," AMERICAN MACHINIST, *October 21, 1957.*

The broad evaluation of the progress of automation in industry in the nine-year period since the work was first used. Based on the editor's experience in reporting developments during that time, on a special survey of the metalworking industries, and on scores of interviews with men in industry, this special report reviews the extent to which automation is being used in U. S. plants today, the success it has enjoyed, its effect on productivity, and some current applications. In addition, one article assesses the role that plant automation will play in the future.

COST CONTROL

"Getting the Facts to the Foreman for Control" by Paul Scharninghausen, N.A.C.A. BULLETIN, *Section One, April, 1957.*

In setting up cost-control procedures, management too often fails to supply the line supervisor with the accounting tools he needs to maintain a close watch on costs in his department, the author believes. He describes how cost data supplied to foremen at Tung-Sol Electric, Inc. (Newark, N.J.), including daily labor analyses and reports on material usage, controllable overhead, and quality level, have resulted in savings far greater than the extra expense involved.

"How to Ease the Pressure of the Big Profit Squeeze," by W. McNeill, CHEMICAL WEEK, *page 93, January 25, 1958.*

The lean look apparent in many process companies' new-profits column isn't entirely the result of economic pressures beyond management's control. Shrinking profit margins may often be traced to the lack of up-to-date cost-control techniques in more than one phase of a company's operations. Without good controls, rampaging costs can be as damaging as outside economic influences.

That cost controls are sorely needed in many process companies is evidenced by the increasing number of cutbacks in personnel, budgets and production. In most cases, cuts like these are last-minute attempts to save profits.

It usually takes a setback of the kind that industry is now experiencing to convince management people that profits must be continually fought for. Management's weapon: a well-thought-out, well-administered cost-control plan. It can keep operating costs in check, bolster a firm's ability to meet the most stringent emergencies—even widespread business recession.

How to go about adopting such an organized approach to cost cutting is the subject of this report.

"1958 Production Planbook and Buyers' Guide Issue," AMERICAN MACHINIST, *Mid-September, 1957.*

This special issue offers, in condensed form, all the new cost-cutting, production-increasing developments and ideas reported in *American Machinist* during the past year. The material is organized under eight classifications: 1. management and personnel; 2. machining; 3. tooling; 4. pressworking, molding, and casting; 5. inspection, testing, and quality control; 6. assembly, heat treat, and finishing; 7. materials and components; and 8. materials handling and services. Also featured is a buyers' guide to equipment and supplies and a preview of metal-working developments expected in 1958.

"Time for a Fresh Approach to Cost Cutting," by Editors, CHEMICAL WEEK, *page 39, January 11, 1958.*

Increased profits with no increase in sales and little or no capital outlay. That's the attractive proposition that a big segment of the chemical industry is overlooking at a time in its history when it can least afford to do so. So said Ray Reul, coordinator of industrial engineering for Food Machinery and Chemical Corporation's chemical divisions, in talks with editors of *Chemical Week.*

Reul's suggested route to increased profits: more use of the industrial engineer—a specialist in the most efficient use of manpower and facilities. One segment of the chemical industry, he says, isn't using such experts at all, and another is trying a "do-it-yourself" approach (i.e., industrial engineering without industrial engineers). This, in the face of a year-and-a-half-long profit squeeze that may well continue through '58.

In applying industrial engineering, Reul states that you have a choice of teaching chemical engineering to an industrial engineer or teaching industrial engineering to a chemical engineer. You are probably better off teaching chemistry to the industrial engineer, although the alternate plan may work.

"The important thing," says Reul, "is to try industrial engineering. Part of the chemical industry is profitably doing so now. The rest of the industry can improve its profit picture by following this lead."

25 Ways to Ease the Squeeze on Profits," by Marilyn French, AMERICAN BUSINESS, *April, 1957.*

A report on what a number of large companies are doing to cut down on office and administrative costs. Among the effective steps they have taken are: 1. reducing the number of reports coming into headquarters by simplifying the financial reporting system; 2. intensifying clerical work analysis and simplification programs; 3. installing tighter budget controls; 4. making use of more modern equipment; and 5. using a sampling approach in many accounting and data-gathering areas.

GENERAL

"Diagnosis of Management Problems," by E. T. P. Watson, HARVARD BUSINESS REVIEW, *page 69, January-February, 1958.*

Executives, long trained in the art of doing and immersed in the day-to-day operation of a company, seldom can take time to examine ways in which the theory of administration can be of help to them in solving the pressing problems of a modern industrial enterprise.

The author urges that top managers check their thinking against the essential ingredients of these processes—setting objectives, organization, control, and planning—instead of treating a drop-off in sales as though it were completely a sales problem, or treating production weaknesses as if they were unrelated to the business as a whole. Using this approach, he sets up a hypothetical top manager and carries him step by step through the job of examining these basic functions of administration.

"Guides to Internal Profit Measurement," by Gordon Shillinglaw, HARVARD BUSINESS REVIEW, *March-April, 1957.*

A reliable method of measuring the profit performance of individual divisions is essential to effective decentralization, says the author. Discussing various techniques of profit measurement, cost recording and analysis, and internal transfer pricing, he concludes that the "controllable profit" concept is the most useful approach to division-profit evaluation.

"How Can Offices Meet the Rising Costs of Production?" by Harry L. Wylie, THE OFFICE, *March, 1957.*

Although there is no pat answer to the question of whether to buy or lease office equipment, in many situations a company can benefit by using the leasing method to obtain cost-saving modern equipment without having to wait for traditional budgetary appropriations, says the author. He discusses the effect of tight money and the liberalization of depreciation rates on equipment leasing trends and presents tables comparing net operating charges involved in buying equipment or using either of two leasing methods.

"Industrial Diagnostics," by J. M. Juran, THE MANAGEMENT REVIEW, *page 79, June, 1957.*

Industrial problems classify themselves, for planning purposes, into two major groups: problems of maintaining the status quo, and problems of changing the status quo.

The steps for maintaining the status quo follow an unvarying sequence:

1. Establishing a standard of performance, whether by executive fiat or by common consent.
2. Setting up a systematic means for measuring and summarizing actual performance, using the "regular" score-keepers.
3. Interpreting the departures of actual performance from standard, done by the line supervision responsible for meeting the standard.
4. Decision on what to do about the departures, also by the line supervision.
5. Action to restore the status quo, also by the line supervision.

Owing to the rapid growth and change in the character of industry, a great deal of managerial effort is devoted to changing the status quo—to reducing costs, increasing sales, improving morale, reducing the accident rate, increasing inventory turnover, etc. The essential approach to this type of problem can be summarized in a sequence of three stages:

1. Discovery of the problems, i.e., of what elements of the status quo need improving.
2. Diagnosis, to determine what changes are needed to bring about an improvement.
3. Remedy, i.e., carry out the changes.

"Modernization Makes a Million," by William M. Stocker, Jr., AMERICAN MACHINIST, *April 8, 1957.*

A two-phase improvement program, begun in 1955 by a large manufacturer (American Bosch Division of American Bosch-Arma Corporation, Springfield, Massachusetts), is saving the company $900,000 annually and providing sizable contingent benefits, the author reports. This article describes the planning and operation of the program, which covers both manufacturing controls and plant facilities and layout.

"The Case for Benevolent Autocracy," by R. N. McMurry, HARVARD BUSINESS REVIEW, *page 82, January-February, 1958.*

The author states, "I have recently participated in the appraisal of nearly 1,000 top-level and middle-management executives, and I have become conscious of the extent to which middle management is composed principally of security-conscious, anxious, and, for the most part, ineffective people who want all the trappings of authority but are very reluctant to exhibit it when the chips are down. Finally, I have come to the conclusion that it just isn't possible in business to delegate much autonomy below the top echelons of management."

After measuring the participative management ideal against the intensely practical yardstick of how well it works, Mr. McMurry goes on to construct a case for his "benevolent autocracy," and shows how he feels it can be instituted.

"The Benefits of 'Batching,'" by Ralph W. Fairbanks and Jerome Hoffman, OFFICE MANAGEMENT, *October, 1957.*

One group of relatively unskilled workers can do the major part of almost any office's work, the authors maintain, by using the technique of "batching" the simple tasks and processing all items as a group in step-by-step fashion. Complex jobs, they say, can be handled by more highly skilled workers, and part-time workers can accomplish the rest after very little training. This article describes the operation of this technique, which, in the authors' view, will increase production and eliminate peakload crises in clerical tasks.

MATERIALS HANDLING

"Here's How Machines Take Over in the Modern Warehouse," by J. J. Brown, CANADIAN BUSINESS, *April, 1957.*

To eliminate the warehousing bottleneck, the same mechanized, high-volume methods that have revolutionized production must be applied to this function, the author believes. Concentrating on the input side of the warehouse operation, he describes some equip-

ment and systems that can improve the efficiency and speed of unloading goods from boxcars or trucks, conveying them to their proper storage point, and arranging them so that orders can be made up on a first-in, first-out basis.

"The Case of Single-Story vs Multi-Story," by *A. T. Gaudreau*, FLOW, *August, 1957*.

Improvements in materials handling equipment and structural design have brought back some of the popularity enjoyed by multi-story plants before the wide-spread swing to single-story buildings during World War II, the author reports. However, he cautions, a choice between the two types of plants depends on specific needs and circumstances, and he lists some of the advantages of both types in terms of capital investment, cost of operation, production facilities, and materials handling activities.

"Toy Train Inspires Automatic Assembly," by *G. C. Thomas*.

A "Toy Train" system of in-process handling is cutting costs by carrying meter assemblies through ten assembly operations with only one manual operation. Further, it is extremely flexible in terms of its own construction as well as the jobs it can do.

At a glance, the system looks like a regular assembly line, but with few people. A second look shows you a master control panel and a monorail which runs the length of the line and then returns in a long oval to the beginning of the line.

Riding the monorail, starting and stopping and entering the machines, one after another, are little carriers. Unlike the toy train, each is powered. It is a whole string of locomotives. Like the toy train, however, each gets its current from the rail.

The principal handling benefit is the cut in index time. The ideal in any assembly operation is to have materials arrive at work stations exactly as they are needed to be fed through as fast as the machines can handle them. This is what the toy train system does.

It is accomplished by having one carrier, bearing its cargo of meter components, always in a work station, being processed, and another always right behind it, waiting to be processed. Total number of carriers is based on two per work station plus some extras for the return loop of the rail.

OPERATIONS RESEARCH

"Evolution of Linear Programming Computing Techniques," by *W. Orchard-Hays*, MANAGEMENT SCIENCE, *page 183, January, 1958*.

While the linear programming concept and the formulation of a specific model have value in themselves, the technique would fall short of its promise without efficient computing procedures. The simplex method has proved to be the most successful approach but it still leaves a wide range for detailed algorithms. At first, the method was applied by hand or with the aid of punched-card equipment. With the advent of internally-stored-program computers, automatic routines were designed. However, the early machines were adequate only for small problems and the original simplex method was not efficient for many LP models. A program of development was started at Rand to provide better computing techniques. Using first the IBM Model II CPC, then the 701 and now the 704, general LP routines of considerable power and flexibility have been developed. Future improvements will probably be possible only from higher level abstractions which take advantage of structure in the model matrix or which produce more efficient forms of the inverse of a sparse matrix.

"Notes on the Theory of Dynamic Programming—Transportation Models," by *R. Bellman*, MANAGEMENT SCIENCE, *page 191, January, 1958*.

The purpose of this paper is to illustrate some applications of the functional equation technique of the theory of dynamic programming to a general class of problems arising in the study of networks, particularly those arising in transportation theory.

"On a Class of Minimum Cost Problems," by *W. Karush*, MANAGEMENT SCIENCE, *page 137, January, 1958*.

The following type of problem has arisen in various contexts in applications of management science: to determine a program of future levels of activity (e.g., production or employment) subject to known future requirements, which will minimize the total cost of the projected program over the entire planning interval of time. Mathematical methods have been developed for treating variants of this problem, and the purpose of this paper is to present an outline of methods appropriate to problems which share a certain common mathematical form.

"Programming of Economic Lot Sizes," by *A. S. Manne*, MANAGEMENT SCIENCE, *page 115, January, 1958*.

This paper studies the planning problem faced by a machine shop required to produce many different items so as to meet a rigid delivery schedule, remain within capacity limitations, and at the same time minimize the use of premium-cost overtime labor. It differs from alternative approaches to this well-known problem by allowing for setup cost indivisibilities.

"The Prospects of a Unified Theory of Organizations," by *O. Helmer*, MANAGEMENT SCIENCE, *page 172, January, 1958*.

Despite the success of numerous efforts in the study of organizations, there is at present no unified theory of organizations. This would require a clearcut conceptual apparatus and a methodology for prediction. To achieve the former within the foreseeable future it might be wise to tie into the existing terminology of game theory; the latter may require taking a new look at the psychological problems involved and introducing something like an operations research approach to them.

"Value Analysis Issue," PURCHASING, *May, 1957*.

This special issue devoted to value analysis is designed to help both small and large companies gain the maximum benefits from this cost-cutting technique. In addition to articles on analyzing component parts and materials, gaining supplier cooperation in value analysis, analyzing price increases, "selling" the value analysis program, and other aspects of the subject, there is a section of 500 brief case histories describing specific ways in which companies have achieved savings and production improvements through their use of the techniques of value analysis.

QUALITY CONTROL

"Automatic Statistical Filling Control," by *W. C. Frey and W. M. Spencer*, INDUSTRIAL QUALITY CONTROL, *page 13, February, 1958*.

This article discusses the problem of a production line method for controlling the fill count of a bottle of pills by means of weight measurement—also the methods of controlling raw materials and pressing methods so that the variability in total weight wouldn't be greater than the weight of a single pill.

"Statistical Method and the Quality Problem in the Soviet Union," by *J. A. Gwyer*, INDUSTRIAL QUALITY CONTROL, *page 9, February, 1958*.

The article was written to give a bird's-eye view of the progress of statistical quality control in the U.S.S.R., based on a review of unclassified literature. This literature is available to anyone who is willing to consult Russian technical periodicals. It is not the author's purpose to measure in depth the extent of the U.S.S.R.'s interest in quality control. This would require a considerably more

penetrating search of the literature than the author's survey represents. The author's intent is simply to give the reader a general insight into what is developing in Russia and thus to stimulate interest in a subject of far-reaching importance.

BOOKS

AUTOMATIC CONTROL: A SCIENTIFIC AMERICAN BOOK, *Simon and Schuster, New York, 1955, 148 pages, $1.00.*

In this volume, compiled from articles originally published in the magazine *Scientific American*, 12 distinguished scientists discuss the essential principles of automatic control, its current applications in industry, and the major lines of development to be expected in the future.

HANDBOOK OF LAYOUT AND DIMENSIONING FOR PRODUCTION, *by H. H. Katz, Allied Institute of Technology, Chicago, Ill., published by the Macmillan Co., 60 Fifth Ave., New York 11, N.Y., 479 pages.*

Industry-defined layout and dimensioning procedures are stressed in this book. All steps in product development, from technical sketch of final drawing, are illustrated and detailed in terms of procedures, principles, and theories. The relationship of each step to efficient mass production is discussed.

Major sections include layout practices, sketching, projective and descriptive geometry, layout applications, dimensioning principles and applications, datums, and elements of gaging.

MAKE OR BUY: FACTORS AFFECTING EXECUTIVE DECISIONS, *by Alfred R. Oxenfeldt, et al. McGraw-Hill Book Company, Inc., New York, 1956, 99 pages, $15.00.*

The first of a series of Consultant Reports on Business Problems, this study analyzes the procedures employed by management in deciding whether to make or buy company supplies. The authors conclude that the heaviest losses usually result from decisions to make what could be more advantageously purchased, and that the current "do-it-yourself" trend in business, a by-product of the merger movement, may hold dangerous pitfalls for management.

MODERN METHODS OF PLANT MANAGEMENT, *Factory Management and Maintenance, McGraw-Hill Publishing Company, Inc., New York, 1957, 128 pages, 50 cents.*

Among the topics covered in this handbook, compiled from monthly issues of *Factory Management and Maintenance*, are plant organization and maintenance, inspection and quality control, materials handling and plant layout, automation, work measurement and wage incentives, and production cost-cutters.

NOTES ON ANALOG-DIGITAL CONVERSION TECHNIQUES, *edited by Alfred K. Susskind, published by The Technology Press of M.I.T., Cambridge, Mass., 417 pages.*

Designed for practicing engineers, this book includes an introduction to the theory of sampling, quantizing, and coding; detailed analysis and evaluation of basic coding and decoding methods for electrical and mechanical analog quantities; and a case study showing how basic principles were applied in a digital flight-test instrumentation system.

PRODUCTION FORECASTING, PLANNING, AND CONTROL, *by E. H. MacNiece, John Wiley & Sons, Inc., New York, 1957, 374 pages, $8.25.*

Included in this second edition are new materials on automation, operations research, and production levels in relation to the guaranteed annual wage, as well as a first-hand report on production engineering education and practices in Europe. The basic principles and techniques of production management are examined with an eye to their economic and social implications as well as their engineering aspects.

THE MATERIALS HANDLING HANDBOOK, *edited by Harold A. Bolz and George E. Hagemann. Ronald Press, New York, 1,250 pages, $20.*

This latest volume on materials handling is said to be one of the most complete reference works available on the subject.

Illustrated with photographs, charts, tables and diagrams, the work is divided into 47 sections covering methods of analyzing handling problems, principles, procedures and techniques for effective operation and control; systems design and installation; integration of materials handling activities with the manufacturing processes; plus the design, selection and classification of materials handling equipment.

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This book clearly explains and illustrates fundamental methods and thinking essential to planning and setting up for effective automation. It shows how to solve problems likely to be met in installing automation—how to combine machines and equipment already in the shop—where to look for possibilities of applying feedback control—how to solve new maintenance problems and personnel problems associated with automation. In short, it guides you in every practical aspect of automation. Every major area of plant operation which is affected—including production, maintenance, cost control, administration, methods, and inventory—is covered in a really practical way.

Order from:

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CONFERENCE AND CONVENTION

The Ninth Annual Conference and Convention of AIIE will be held:

Los Angeles, California

Hotel Statler

June 12, 13, and 14, 1958

PLAN NOW TO ATTEND

Institute Interests

CALENDAR

June 1-6: Ninth Annual Industrial Research Conference; Columbia University, New York, N.Y. Write Robert T. Livingston, Director, Department of Industrial and Management Engineering, Columbia University, New York 27, New York.

June 9-20: Intensive Course in Operations Research and Systems Engineering sponsored by the School of Engineering of the Johns Hopkins University, Homewood Campus of the University. Write Dean, School of Engineering, The Johns Hopkins University, Baltimore 18, Maryland.

June 10-20: Advanced Short Course in Quality Control by Statistical Methods is being held at Purdue University for 12th consecutive year. Limit 50 enrollees. Write Professor Irving W. Burr, Statistical Laboratory, Purdue University, Lafayette, Indiana.

June 17-20: Annual Cornell University Industrial Engineering Seminars sponsored by the Department of Industrial and Engineering Administration, Sibley School of Mechanical Engineering, Cornell University. Write Dr. Andrew Schultz, Jr., Department of Industrial and Engineering Administration, Cornell University, Ithaca, New York.

June 15-28: Fifth Annual Materials Handling Training Conference; Industrial Management Center, Lake Placid Club, New York. Write James R. Bright, Director, Industrial Management Center, 56B Robbins Road, Lexington, Massachusetts.

June 16-26: Fifth Annual Southern Regional Graduate Summer Session in Statistics, Oklahoma State University, Stillwater, Oklahoma. Write Dean of the Graduate School, Oklahoma State University, Stillwater, Oklahoma.

June 18-21: The Western Regional Leadership Laboratory in Human Relations and Supervisory Skills; University of California, Santa Barbara Campus. Write Department of Conferences and Special Activities, University Extension, University of California, Los Angeles 24, California.

July 21-August 16: Survey Research Techniques; University of Michigan Survey Research Center, Ann Arbor, Michigan. Write Survey Research Center, University of Michigan, Ann Arbor, Michigan.

September 8-19: Industrial Engineering Intensive Courses—Basic; Washington University, St. Louis, Missouri. Write University College, Washington University, St. Louis 5, Missouri.

September, 1958: Fourth annual offering of the Engineering Executive Program starting in September; U.C.L.A. Write Engineering Executive Program, Department of Engineering, University of California, Los Angeles 24, California.

October 30-November 1: 1958 Northeastern Regional Conference, Syracuse.

PRESIDENT CARSON HONORED AS MAN-OF-YEAR

Dean Carson, President of the American Institute of Industrial Engineers, Inc., was selected recently as the Technical Man-of-the-Year by the Columbus Technical Council.

Following are excerpts from the February 21, 1958 issue of the *Ohio State Journal*, which will be of interest to chapter members:

Selection of Dean Carson as recipient of the Council's annual award was announced at Winding Hollow Country Club during the annual banquet for members of the 24 technical organizations comprising the council. . . .

The OSU educator was chosen for the honor on the basis of his outstanding career as an executive and engineer in private industry, and as a college educator and research worker.

He was presented with a scroll and a U.S. savings bond. . . .

Dean Carson became the second recipient of the Council's annual award. Its first presentation last year was made to Dr. Robert B. Filbert, chief of the chemical engineering division of Battelle Memorial Institute.

The head of OSU's engineering college was for many years a member of the faculty at Case Institute of Technology at Cleveland and later an executive of the Selby Shoe Co. at Portsmouth before joining the university here.

Dean Carson was graduated from Case in 1931. He then went to Yale University as a graduate assistant and later returned to Case to serve as an instructor, assistant professor and associate professor. He received his master's degree in mechanical engineering from Yale in 1938.

At Case, Dean Carson developed the curriculum for the graduate program leading to the master's degree in Industrial Engineering. At the same time, he also served as a research engineer and director of research for the Cleveland Automatic Machine Company.

He left Case in 1944 to become assistant to the general manager of Selby Shoe Company. He later became manager of engineering and then secretary. He has invented several devices used in shoe manufacturing, and has patents pending on other items in connection with the automation of consumer goods production.

At Ohio State, Carson also is director of the Engineering Experiment Station and vice president of the Research Foundation. He is chairman of the State Selective Service Advisory Board for Scientific, Technical and Specialized Personnel, and a member of numerous technical and professional organizations. He is married, has four children and lives at 2125 Elgin Road, Columbus.

GILBRETH LIBRARY

Industrial Engineers around the world are invited to visit the Gilbreth Memorial Library which has been established in the Industrial Engineering Department of Purdue University.

This collection is possible because of the generosity of Mrs. Lillian Gilbreth who in 1939 presented to Purdue University the private professional library of her husband. To this collection Mrs. Gilbreth, an eminent member of our profession, has contributed supplementary material so that this library now presents one of the greatest sources of information for Industrial Engineering research.

One will find in this collection all of the classics in the fields allied to Industrial Engineering. Many of these volumes have marginal notations made by Mr. Gilbreth which give an exciting insight to his perception of modern Industrial Engineering. Contained in this collection are many slides and pieces of equipment used in his studies. Most revealing is the extensive "information" or "N" files which contain a wealth of information about Industrial Engineering.

Frank Bunker Gilbreth was born in Fairfield, Maine, on July 7, 1868. When he was but a young child his widowed mother moved first to Andover and then to Boston to give her children the advantages of a better education. Although Gilbreth showed better than average ability in school, he elected to enter the building trades as a brick-layer rather than go to college. He was eminently

successful and soon was a contractor in his own right. Nor did he ignore his inventive abilities, for during this time he developed aids for construction, such as concrete mixers, dry basement designs, and others, which he sold by pioneering advertising techniques. Early in his life Gilbreth started his pursuit for "the one best way" which was later to absorb most of his energies.

The Industrial Engineer of today must live in continual gratitude to his imaginative and creative ability. His professional ethics determined the standard for the Industrial Engineering profession. It is therefore the purpose of the Gilbreth Library to serve as a shrine for the memory of this great engineer, and also, as he would wish, a source of stimulation for scholarly contributions. You, as an Industrial Engineer, will be welcomed to the Gilbreth Library at Purdue University. For further information please write Professor H. T. Amrine, Head, Department of Industrial Engineering, Purdue University, West Lafayette, Indiana.

RESEARCH INFORMATION

The Research Information Committee of the American Institute of Industrial Engineers is starting to secure abstracts of research performed in the period 1 July 1952 to 1 July 1957. Sources from which information will be solicited are universities, industrial organizations, research institutions, and non-profit organizations, including government agencies and professional societies. The information collecting program will provide a valuable service to industry and universities and especially to Industrial Engineers. Research abstracts are to be collected in the areas of:

WORK MEASUREMENT
METHODS
PLANT ENGINEERING
HUMAN ENGINEERING
ENGINEERING ECONOMICS
ORGANIZATION PLANNING
INDUSTRIAL STATISTICS
PRODUCTION CONTROL
DATA PROCESSING
OPERATIONS RESEARCH
COST ANALYSIS

The committee will appreciate all information on Industrial Engineering research past and present, about which it might gather more specific details. Write: Research Information Committee, AIIE Department of Industrial Engineering, Washington University, St. Louis 5, Missouri.

CENTRAL ILLINIOIS CHAPTER

We are Chapter 80 in the AIIE, and our charter is dated January 13, 1958. Our area encompasses fourteen counties in Illinois, from Ottawa in the north to Springfield in the south. At present our headquarters is in Peoria, but we hope to attract members from the entire area, and hold meetings in different cities from time to time.

The first official technical meeting of our Chapter was on March 10, at which time our regional Vice President, Dr. Marvin Mundel, formerly presented our Charter and addressed us on the subject "Functions of Industrial Engineering." Among other points, he emphasized the advantages to be derived from membership in AIIE. This was primarily directed at the large number of prospective members in attendance.

We are currently planning an extensive membership drive under the able leadership of Cliff Gillett, our membership Chairman. Wide use has been made of the AIIE membership kits and information brochures, with distinct success. Our Program Chairman, Frank Mergen, is making preparations for our first fall conference, to be held at and co-sponsored by Bradley University's Industrial Engineering Department. Arjay Platt, our Publicity Chairman, has been rather severely hampered in his efforts to inform the residents of Central Illinois, and especially Peoria, of the existence of an AIIE Chapter, because of the prolonged strike of our one and only Peoria newspaper. Because of this our publicity has been almost entirely by mailings and personal contact.

Our temporary officers, serving until elections in April, are L. J. Fletcher, Jr. President; A. J. Knarb, Vice President; D. J. Knaub, Secretary; and Homer Smith, Treasurer. Bob Maier served as Chairman of our nominating committee, a most difficult job at this stage in our chapter development, as few of the members know each other personally.

We are a small chapter, newly organized, but we have great plans for the future. Watch the Central Illinois Chapter!

CHICAGO CHAPTER

Frank Wier, General Superintendent of Materials Handling for the Timken Roller Bearing Company at Canton, Ohio, was the guest speaker at the January meeting. The subject of Materials Handling proved to be an interesting one for members and guests. Attendance and participation at the meeting were evidence that the subject and speaker were well received. The Chicago Chapter is grateful to Mr. Wier for his presentation and for taking the time to make the trip.

In December the Chicago Chapter of AIIE made another stride toward its goal of providing its members with programs designed to familiarize or increase their knowledge of the tools and techniques of this expanding profession. The Western Society of Engineers in Chicago's loop provided the scene for a one-day conference on "Work Sampling." The program was ably conducted by Professor Wallace J. Richardson of Lehigh University. Prof. Richardson, besides being a recognized consultant in the field of Work Sampling, is also co-author of an excellent book on the subject. Each of the approximately 40 persons present received copies of Prof. Richardson's book, *Work Sampling*, which was used as an outline for conducting the program. The morning session was primarily devoted to the introduction and explanation of the uses of sampling techniques as applied to work measurement. The afternoon session featured a group participation example of how sampling techniques function. As a conclusion to the program, Prof. Richardson held a short question and answer session. This served to put the finishing touches on a very interesting and informative conference.

DAYTON CHAPTER

Our January meeting was held in the ROTC building at the University of Dayton on Monday, January 20. Our speaker and honor guest was Dr. Marvin E. Mundel, Vice Director of the Management Center of Marquette University. Dr. Mundel spoke most interestingly on the subject "Memomotion Study."

DETROIT CHAPTER

The Conference on "Work Measurement In the Plant and In the Office" held January 23 and 24 was a huge success. The enthusiastic support given by various organizations in this area to the first AIIE sponsored conference indicated the great potential for growth of our Chapter and the AIIE. As a result of the conference, 25 applications for membership have been received. Proceedings of the conference are being compiled and will be available shortly. Anyone interested in obtaining a copy of the proceedings may do so by sending $3.00, name, and address to H. Brumback, Industrial Engineering Dept., Great Lakes Steel Corp., Ecorse, Michigan.

We are very proud to announce that Arthur D. Even, one of our Chapter members, was awarded the Dept. of the Army Commendation for Meritorious Civilian Service, the second highest award granted to a civilian, for his outstanding performance in designing an improved recorded-keeping system and data processing system. This system is to serve as a pilot for similar

systems to be adopted world-wide at other Ordnance Commands and installations.

Central Region Vice President, Harold T. Amrine, was present at our February meeting. At this same meeting, Mr. Donald R. Bolle, Director of Planning and Scheduling, Materials Handling Systems, Inc., spoke on "Recent Developments in Materials Handling." The March meeting was devoted to Industrial Applications of Operations Research." Speakers for this meeting were Roger B. Crane, Director of Management Sciences, and Dr. George B. O'Brien, Manager of Operations Research, both of Touche, Niven, Bailey and Smart.

JACKSONVILLE CHAPTER

Our speakers at the various meetings so far this year have all been quite outstanding. In September, E. P. Martinson, Director of the Department of Industrial Engineering at the University of Florida, spoke to us on "Industrial Engineering Progress." At the October meeting, Mr. Bernard L. Meyer, who is Industrial Engineer at the Meyer Fish and Produce Company here in Jacksonville, told us about "Industrial Engineering Applications in the Food Processing Industry." The November meeting took the form of a "Plant Tour of Florida Machine and Foundry Company," featuring University of Florida Student Chapter guest Thomas Peacock, who is Works Manager of the Company. In December, Emmett L. Cochrane, Industrial Engineer, of the Public Works Dept. at the Naval Air Station here in Jacksonville, spoke to us on "Controlled Maintenance." "Industrial Expansion in Florida" was the subject of January's meeting. Mr. Harold Colee, Vice President and General Manager of the Florida State Chamber of Commerce, was guest speaker. The featured speaker at our February meeting was Tom Peltier, Engineering Management Services Division, Ernst and Ernst, Atlanta, Georgia. His topic was "Slicing Costs Through Better Inventory Control."

LOUISVILLE CHAPTER

A handy group of AIIE members, their wives, and a few visitors were guests of Brown-Forman Distillers on December 11, 1957. Serge Birn took us on an interesting exploration of the vast regions of the underwater area of our planet by way of color slides he took while vacationing in the Bahamas, the Virgin Islands and on the French Riviera. In addition to the excellent color photography and interesting commentary on the pictures, Serge also presented a display of equipment used in skin-diving, spear-fishing and under-water photography. After the program, we were guests of Brown-Forman for coffee, soft drinks and sandwiches.

Professor Harold T. Amrine, head of the Industrial Engineering Dept. of Purdue University and Vice President of the Central Region of AIIE, spoke briefly at our January meeting. Principal speaker at the January meeting was Mr. Gray L. Carpenter, President of Gray L. Carpenter & Associates, Management Consultants, New York, New York, who spoke on "New Trends in Management Thinking." He discussed the immediate business outlook as predicted by Matt Murphy in "Factory Management." He said that 1958 and 1959 will give Industrial Engineers an opportunity to show their ability to effect cost reductions and thus aid in helping business ride out this slump or submit to the pressure of the marketing group, who are currently selling management on their scheme for riding out the slump. Industrial Engineers should find out what ammunition is available for reducing costs. No single method is good enough for 1958, and the I. E. must keep himself abreast of new techniques. Some phases noted by Mr. Carpenter were: Organization analyses, Management development, Standardization of maintenance and clerical work through the use of predetermined time standards.

MEMPHIS CHAPTER

For our January meeting, the Chapter took a conducted Mill Tour of the Buckeye Cotton Oil Plant here in Memphis. This was most informative, as well as enjoyable.

The February meeting was held at the Highland Heights Branch of the Union Planters Bank. Our speaker was Mr. E. C. Stimbert, Superintendent of the Memphis Public Schools. His chosen topic was "Accent."

During Engineers Week in February, our Chapter accepted the responsibility of depicting the Engineers' Contribution toward Progress, through the medium of posters. These were displayed prominently in windows throughout the downtown area.

METROPOLITAN NEW JERSEY CHAPTER

Gordon Carson was guest and principal speaker at a March 24 dinner meeting of our Chapter. Other invited guests included Mr. Harry Davis, Eastern Region Vice President, Elmer Easton, Dean of Engineering, Rutgers University, and Dr. Lillian Gilbreth. Governor Robert Meyner of New Jersey proclaimed March 24 as Industrial Engineering Day in the state. This proclamation was read at our meeting.

MID-HUDSON CHAPTER

Members of the Organizing Committee of the Mid-Hudson Chapter of the American Institute of Industrial Engineers as they finalized plans for the Charter meeting to be held in the Central Hudson Auditorium, 47 Canon Street in Poughkeepsie at 7:30 P.M. on Thursday, October 17, 1957.

MILWAUKEE CHAPTER

We have had a most interesting and educational line-up of programs this year. In September, Ray Klockzim spoke to us on "Industrial Engineering and Management in Japan" at our meeting held at Marquette University Management Center. The October meeting took the form of a dinner followed by a plant tour and discussion of the Harnischfeger Corporation, heavy machinery manufacturing concern. Mr. D. Drewery was speaker on this occasion. In November, Mr. D. G. Malcolm, past national president of AIIE, spoke on "Operations Research"; again at Marquette University Management Center. At our January meeting, a panel from the Milwaukee area discussed "Cost Reduction—New Techniques." Dr. M. E. Mundel was our speaker for February; he took as his topic, "Allowances for Weight in Time Study." In addition to our regular March meeting, where "Statistics in Industrial Engineering" was the subject under discussion, the Chapter also took a daytime plant tour through Giddings and Lewis Machine Tool Company of Fond du Lac. The trip featured "Numerecord Control on Skin Milling." At our April meeting, Mr. J. Conway's talk on "Industrial Training" was followed by the election of officers for the coming year. The May meeting featured a social hour, dinner, installation of new officers and a talk on "Human Engineering."

MOBILE CHAPTER

The formal presentation of Charter and installation of permanent officers of the Mobile Chapter, AIIE, took place on February 13 at a dinner meeting at the Admiral Semmes Hotel. James T. French, Southeastern Regional Vice President, presented the Charter and officiated at the installation. Col. Frank F. Groseclose, Director of the School of Industrial Engineering, Georgia Institute of Technology, and past national President, AIIE, was featured speaker. His subject was "People, Places and Things—Engineering."

Officers of the Mobile Chapter are: President, N. K. Rogers; First Vice President, W. E. McKay; Second Vice President, T. M. Warschauer; Secretary, J. J. Barnes; Treasurer, J. P. Jones.

PHILADELPHIA CHAPTER

For the first meeting of 1958, the Philadelphia Chapter was honored to have as its speaker, the well known author and consulting engineer, Mr. Phil Carroll. The subject of his lecture was "How to Cut the Costs of Setting Standards" and was presented to the largest audience of the current season on Wednesday evening, January 15.

Mr. Carroll indicated that there are two methods of using time study to measure work; namely, 1. rate setting, that is, time study of every job and 2. standard data application. There are two errors which arise in the use of rate setting method: those which are caused by the selection of elements and those errors introduced by performance rating. According to Mr. Carroll, it costs about seven times as much to set standards by the rate setting method as compared to use of standard data. In addition, the coverage which can be obtained with the former method is about fifty percent. The only way coverage can be increased is to set the standards before the jobs are processed by using standard data.

Since consistency is more vital than accuracy and in the interest of saving clerical time and reducing the chance of errors, Mr. Carroll recommended the use of standard data. In order to demonstrate the potential of this method, Mr. Carroll distributed passouts which enabled the members of the audience to follow an actual example of development of time study data from which standards could be issued. A lively discussion period followed Mr. Carroll's presentation.

On Wednesday evening, February 19, the Philadelphia Chapter presented the Rev. Stephen F. Latchford, S.J., who spoke on the subject of "The Problem of Union Leadership." Father Latchford currently is assistant director of the Institute of Industrial Relations of St. Joseph's College in Philadelphia. He is a graduate of Georgetown University and after spending several years in Jamshedpur, India, returned to the states and received his M.A. in industrial relations.

Father Latchford believes that the labor leader today must be an idealist who is dedicated to the service of the members of his organization and not to his own personal gain. Much of the misconduct of certain labor leaders brought to light by the recent Congressional investigations has been the result of a shift in the interest of the labor leaders from the welfare of their members to their own personal and material wealth. However, the labor movement should not be characterized by the people who make the headlines with their misdoings. As Father Latchford pointed out, there are many instances where individuals and organizations are doing excellent jobs but do not receive any publicity.

SEATTLE CHAPTER

The January meeting of the Seattle Chapter was devoted to Automation. A sound film was presented, and an active question period was led by Sam Nelso, Applications Engineer for the General Electric Company. Emphasis was on the step by step introduction of automated sections of a production process, and applications to industries which although not mass production plants have volume runs of some parts or products.

On January 20, a visit to the new Seattle Terminal Post Office was scheduled.

Programs have been lined up for the first half of 1958 and printed programs issued. Of particular interest is the March program which will be devoted to presentation of the winning entries in the second annual Technical Paper Contest for members of Seattle Chapter. Prizes start at $100 cash. Last year's winning paper by Edwards R. Fish, Jr., P.E. of Northwestern Glass Co., was published in the Nov.-Dec. 1957 *Journal*.

Plans are well under way for the Fourth Annual Cost Reduction Conference under the chairmanship of Jerry Watson, Boeing Airplane Company. Tentative dates are April 11 and 12.

Monthly meetings are held on the second Wednesday at the Stewart Hotel, Seattle.

ST. LOUIS CHAPTER

The Midwest Regional Cost Reduction Conference and a special reception for Dr. Lillian Gilbreth have highlighted the Spring program of the St. Louis Chapter.

Under the direction of Charles Wicks, the attendees at the three-day conference on cost reduction heard representatives of industry, government and the armed services describe modern cost reduction techniques. Mr. Ralph Hardin, USAF Air Research and Development Command, described the effect on the technical manpower crisis of management cost control. Dr. Marvin Mundel discussed the Industrial Engineer's role in modern management. The opening session banquet heard the Honorable Raymond R. Tucker, Mayor of St. Louis and professional engineer, explain the cost of good government.

Mr. R. P. Muller of IBM Corporation, Dr. J. D. Hanawalt of Dow Chemical Company, Mr. H. C. Johnson of Ford Motor, Mr. J. M. Allderige, of Eastman Kodak, Mr. O. S. Hully, of General Electric and Mr. W. A. Watt, of Motorola Incorporated, joined Dr. William Gomberg, of Washington University, and Mr. Walter Burk, of McDonnell Aircraft, in presenting other techniques and ideas to those in attendance.

In February, local members and their wives attended a reception for Dr. Lillian Gilbreth during her two-day visit to Washington University. Dr. Gilbreth spoke on Industrial Engineering Around the World and later appeared on KETC, the St. Louis educational television station.

The regular February meeting heard Mr. Robert Cummings of Union Bag-Camp Paper Corporation's Savannah, Georgia, plant present a highly informative program on Brainstorming.

Mr. James Biggane, of the Maytag Company, was the January speaker. His program was a fine description of the application of planning, scheduling and management of maintenance work at the Maytag Company. Mr. Biggane last spoke to the local Chapter during the 1955 national AIIE convention held in St. Louis.

The final programs of the year are the Washington University students night and the annual spring dinner-dance.

The Department of Industrial Engineering and the University College of Washington University in St. Louis are co-sponsoring some Industrial Engineering Intensive Courses—Basic from September 8 through September 19, 1958. They are intended for personnel desiring a basic introduction to the subject of the course. The objectives of the course will be to help prepare the participants to apply the course concepts in their own organizations, and to help train others in their companies in the principles of the course. The following subjects will be offered: Quality Control; Motion and Time Study; Elements of Integrated Data Processing; Engineering Economy; Plant Layout and Materials Handling; Production Control; Collective Bargaining for Engineers; Engineering Psychology; Materials and Process of Manufacturing; and Tool Engineering. These courses are being presented with the co-operation of the St. Louis Chapters of AIIE,

MEMBERS OF THE NEWLY ORGANIZED TORONTO-HAMILTON CHAPTER

American Society of Mechanical Engineers, American Society of Tool Engineers, American Society of Quality Control, American Materials Handling Society, Association for Computing Machinery, and Society for Advancement of Management.

TORONTO-HAMILTON CHAPTER

More than 20 prominent Industrial Engineering executives of major organizations in Southern Ontario gave unanimous approval on January 30 to formation of the first Canadian Chapter of the American Institute of Industrial Engineers.

Meeting at the Avro Aircraft Limited plant at Malton, where they were guests at a dinner given by the company, the visitors were welcomed by S. L. H. Wilson, Avro's Industrial Engineering Manager.

Guest speaker was M. A. Payne, past president of the national organization, who is now serving as Director of Chapter Expansion for the AIIE.

Mr. Payne outlined the history of the AIIE from its inception at Columbus, Ohio, in 1948, and pointed out the benefits to members in keeping abreast of current developments through the association. He emphasized that these benefits were two-fold in that the organizations with whom the members were associated received the advantage of the latest techniques of the profession. Assistance was also given to students of the profession through the 40 student chapters of the AIIE.

The following temporary officers were elected to carry out the organization of the Canadian Chapter and to report progress at the next general meeting to be held in March: Chairman, W. Graham Eves, Assistant Industrial Engineering Manager, Avro Aircraft Limited, Malton; Vice-Chairman, Paul W. Bennington, Chief Industrial Engineer, Steel Company of Canada, Hamilton; Secretary, John M. Hughes, Staff Consultant, Stevenson & Kellogg, Limited, Toronto; Treasurer, W. J. McQuire, Administrator, Operations Control, British American Oil Company Limited, Toronto; Publicity Chairman, M. Parkinson, Specialist Incentives, Canadian General Electric Company Limited, Toronto; Program Chairman, G. Fisher, Manager, Manufacturing Standards, Ford Motor Company, Oakville; Constitution Chairman, William W. Loucks, Mgr. Works Analysis, Ontario Hydro-Electric Power Commission, Toronto; Qualifications Chairman, G. B. Bailey, Director, J. D. Woods & Gordon, Toronto.

WESTERN VIRGINIA CHAPTER

The Western Virginia Chapter #81 of AIIE was granted a Charter between the initial organizing meeting called by N. H. Friedman on January 15, 1958, and election meeting of February 15, 1958. The following officers and Board members were elected: President, N. H. Friedman, Lynchburg, Virginia; Vice President, W. E. Carroll, Roanoke, Virginia; Secretary, J. F. Lindsey, Blackburg, Virginia; Treasurer, J. H. Crutchfield, Roanoke, Virginia; 2 Year Board, J. E. Hillsman, Pearisburg, Virginia and R. L. Smith, Blacksburg, Virginia; 1 Year Board, B. E. McCauley, Radford, Virginia and R. Downey, Salem, Virginia.

Formal presentation of the Charter took place on March 19, 1958, at the S & W Cafeteria in Roanoke at 7:30 P.M. following the dinner hour. J. T. French, Vice President of the Southeastern Region, made the Presentation.

Chapter meetings will normally be held on the second Wednesday of each month and in all probability will be rotated among various geographical locations which this Chapter covers. The April 9 meeting was held at the S & W Cafeteria and featured a talk by Professor R. L. Smith of V.P.I. on "Statistical Concepts of Organizational Control."

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Edited by CHARLES L. MANTELL, Consulting Engineer
Newark College of Engineering. *1906 pp., 648 illus., $21.50*

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ie opportunities

WHAT IT IS

The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Columbus, Ohio chapter.

SERVICES PROVIDED

Current job openings are published in condensed form in each issue.

In addition, a monthly I. E. Opportunities Bulletin is supplied to over seventy chapters located throughout the United States.

Each job opening is assigned a "P" number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

Industrial Engineers are often employed in such fields as Work Measurement, Production Control, Plant Engineering, Operations Research, Industrial Relations, Sales, and Management. For a more complete coverage, see the following list of job classifications. Please do not hesitate to forward information on jobs in any area where it is recognized that an Industrial Engineering background will be of value.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

This information will be publicized to the members in condensed form in the JOURNAL and in monthly chapter Bulletins. Company names are not shown.

MEMBERS SEEKING JOB OPPORTUNITIES

The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the "P" numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

ADDRESS OF THE SERVICE

I. E. OPPORTUNITIES SERVICE
American Institute of Industrial Engineers
145 North High Street
Columbus 15, Ohio

INDUSTRIAL ENGINEERING OPPORTUNITIES

Position number	Industry, location		Travel?	Job classification number (See key)	Salary	Qualifications required		
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range
								from / to
1	Consult.	Ill	×	Broad			7–10	30 / 38
2	Education	Ga		51, 52, 31, 47		Ph.D.		
6	Warehouse	NJ		94				
12	Steel Bldg. Mfg.	Ind						
17	Air Force	O		11, 13, 42, 31, 38	7.5–9		4–5	
20	Electric, Mfg.	Mo						
21	Education	Mass						
23	Education	NY		10, 30, 40, 52	6–10			
26	Education	NC				M.S.		
27	Education	Puerto Rico		37, 53, 31				
29	Garment Mfg.	Northeast		37, 31				
31	Paper Mill	Wis		11, 45, 80, 70, 32			1–5	30
34	M. Consulting	O	×	30, 40, 53, 71			4	27
39	Education	Neb						
41	M. Consulting	O	×	10, 21, 31			5–7	
42	Hospital	O		10	4.8–7.2			
49	Graphic Arts	Ill		11, 20, 42, 43, 70			3–5	25 / 35
67	Army Ordnance	Pa		11, 13, 34, 71, 72, 73	6.2–7.4		2–3	35 / 55
72	Airline	Ill		70, 42, 43				
75	Army Ord.	Ill		13, 31, 37, 70	7–9		2–4	
79	Mining & Smelt	NM		10, 20, 30, 40			6–9.4	45
81	Chem. Process	O		38, 50, 11	6.0		0–5	19–20
83	Textile Co.	Ga		37, 42, 38	4.8–7.5			30
86	Public Utility	DC		10, 11, 13, 18, 37, 42, 43			2–3	
89	Foundry	Cal						
91	Syn. Fibers & Films	Pa, Va, W Va		10, 20, 42, 43, 72			0–5	
93	Foundry	Ill		11, 19, 30				
106	Sugar	MD, La, Sc, Conn		13, 43			0	
108	Consulting	Overseas	×	10, 20, 60			10	35 / 40
111	Chemical	Ala			7.5			
113	Chemicals	NJ		52				
119	Paper	Ga		10, 20, 30, 42, 43, 53	6.0–7.2			
123	Printing	NY		49, 53			2–4	
125	Chemical	Mich		13, 21, 43, 33			1–5	
137	Copper†	Chile, S A	×	31, 39, 43, 64	9.0		5–	30
140	Magazine-Editorial	Mass		43	5.0–7.0			
141	Steam Electric Power	Toronto		93–80	11.0		13 (P.E.)	35 / 45
145	Lithography	Vt		31			2	

† 3 yr contract

Position number	Industry, location		Travel?	Job classification number (See key)	Salary	Qualifications required		
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range
								from to
155	Electronics	Texas		11, 13			3–	
156	Plastics	Texas						
163	Govnmt Inspection	O		37	6.4–7.5		7–	
164	Precision Mach Shop	Texas		11, 13, 19, 32, 42	6.0–7.2		3–5	35
165	Electro-Mechanical	Calif		11, 13, 19, 42, 53	5.8–		0–3	
166	Paper Mill	Pa		91–16			4–5	
167	Weapons Systems	Wash DC		50		Ph.D.		
168	Education	Mich		92	6.0–7.5	Ph.D./M.S.	1–5	25 55
172	Power Shovels	Pa, Wisc, Ind		11, 13, 21, 32, 39				
174	Highway Dept.	Mich		11, 32, 38, 45, 70	5.3–7.1			
177	Education	NY		50+General I.E.		M.S. or Ph.D.		30 45
179	Education	Tex		I.E. Dept. Head		M.S. or Ph.D.		
181	Bldg. Maint.	Mich		31, 38, 48				
183	Metal. Fabr.	Ind.		13, 21, 39, 42, 48	10.0	B.I.E.		30 40
184	Education	Pa		10, 47, 54, 81				
185	Chem. Plastics & Resins	Conn		50, 52, 37, 30, 36		M.S.	–5	30
186	Chem. Plastics & Resins	Conn		11, 26, 36			1–4	28
187	Glass	Tenn		43, 81				
188	Education	Mass		Asst. Prof. (50)	5.1–6.5	M.S. or Ph.D.		
189	Agric. Marketing	Maine	×	10, 42, 43, 53	7.5		2½	
191	Agric. Marketing	Wash. DC		10, 42, 43, 53	5.3		½	
192	Air Force Base	Ala		11, 13, 15, 16	4.5–7.5			18
193	Pharmaceuticals	Ind		13, 21, 42, 44, 50, 55, 70	5.4			
194	Airline	Cal		11, 31, 36, 42, 43, 45, 71			4–15	25 35
195	Consult.	NJ		10, 20, 31, 42, 54, 70	8–12	B.S.	5	30 45
196	Navy	Pa	×	13, 33, 42	7.4		2½	
197	Aircraft	Wash		I.E.	5–10		2	25 40
198	Paper Converting	Mo		13, 19	6–		5	30 40
199	Govt. Agency	Panama		Engr. Trainee	5.6–6.7			20
200	Electronics	Texas		31, 33, 35, 38, 54, 70	7.2–8.6		3–	
201	Electronics	Texas		42	6.5–7.2		3–	
202	Electronics	Texas		11, 19, 33, 35, 38	6.5–8.0		5–	
203	Electronics	Texas		19, 38	7.2–8.6			
204	Heavy Mtl. Working	NY, Pa, NJ		14, 15, 19, 21			1–7	
205	Heavy Mtl. Working	NY, Pa, NJ		11			5–	
206	Army Ordn. Depot	NJ		10, 11, 13, 15, 16, 21	6.0–8.5		2–	
207	Textile Mfg.	NC-SC		45, 46, 42, 43, 21, 32	9.0–12.0			40
208	Mtl. Stamping Mach.	Wisc		10, 11, 13, 16	9.0–12.0		5–	28 40
209	Consulting	Ill-NY	×	50, 51, 52	9.0–15.0			
201	Mfg.	NY, NJ, Fla, Cal, Ill		54, 50 (Military)	10.0–13.0			
211	Mach. Mfg.	Texas		92–	10.0–15.0			40
212	Metal Fbr.	Ia, Minn, Mich		91	8.0–10.0			37
213	Aircraft Repair & Mod.	Cal		15, 32, 42, 43, 44, 53	7.5		2½	21
214	Airforce Depot	NY		13, 31, 40	4.4–7.4			
215	Air Force	Pa		10–19, 41–47, 49, 52, 54, 70–73	7.4		2	55
216	Air Force	Pa		10–19, 41–47, 49, 52, 54, 70–73, 90, 92	10.0		4	55
217	Air Force	Pa		10–19, 41–47, 49, 52, 54, 70–73, 90, 91	8.6		3½	55
218	Ammunition Depot	Wash		10, 30, 40, 50, 70	7.4		2½	
219	Air Force	Utah		10, 11, 13, 14, 15, 16, 18, 19	7.4		2½	
220	Agric. Service	Ariz, Colo, NM, Utah, Wyo		11, 32, 33, 42, 44, 66	4.5–10.3			
221	Sugar Refining	Conn, Pa, Md		10, 31, 36, 38, 40, 53	5.5–7.2		0–5	30
222	Education	Mont		37, 51, or 54	6.5–7.5		3	24
223	Navy Ship Repair	Guam		94–42, 44, 48, 49	6.4 plus 25%			
224	Paper & Bag	Ala		35, 43, 53, 54				
225	Post Office	Wash DC	×	Ind. Eng.	7.4–11.3		4	
226	Silverware	NY		92–13, 21, 42, 11			10	35 45
227	Heavy Steel Fabr.	O		91, 11, 43, 54, 70	6.0–8.0		5+	35 45
228	Navy Overseas Bases	Pacific						
229	Bakery	Mo, Cal						
230	Heavy Mtl. Working	NY		93–40, 42, 44, 48			5–7	
231	Heavy Mtl. Working	Pa		39			5	
232	Air Transport	Okla		13	5.4–7.4		1–2M	21 35
233	Air Lines	Okla		11, 36, 53	5.8–8.0		4–	25 40
234	Plumbing Goods	WVa or Texas		10			2	
235	Knitting Apparel	NC		10–20	5–8		0–5	45
236	Printing	Ill		31, 32, 33, 34, 37, 38				

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop-Watch Time Study
15	Std. Time Data Dev. & Applic.
16	Predeter. Elemental Time Stds
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

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Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.